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*City Document.*—No. 38.

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# CITY OF BOSTON.

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REPORT ✓

ON SCHEMES FOR

AN ADDITIONAL SUPPLY

OF

# PURE WATER.

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1874.

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## CITY OF BOSTON.

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IN COMMON COUNCIL, April 23d, 1874.

The Joint Standing Committee on Water, who were requested by orders of the City Council, (1) To consider the possibility and expense of obtaining a sufficient supply of water for the city by connecting Mystic pond with Shawshine, Concord and Merrimack rivers, or either of them, by the use of the old Middlesex canal or otherwise; (2) to consider the expediency of making a permanent water-connection between Farm Pond and Lake Cochituate, and constructing a conduit from Lake Cochituate (crossing Charles river by a bridge) to Chestnut Hill reservoir; (3) to ascertain the purity of the water of Charles river at the point where it would be expedient to take the same for the use of the city; (4) to ascertain by accurate surveys the watershed of Mystic pond; (5) to ascertain the number of mills, and the average amount of water required daily by each, on Charles and Sudbury rivers, respectively, as a means of obtaining an approximate estimate of the water damages which will be caused by making use of those rivers for a water supply, — beg leave to submit the accompanying report from the City Engineer, furnishing the information desired under the four orders first named, and the report of Messrs. Warren and Adams of this committee, covering the information, so far as it could be procured, requested in the fifth order.

These reports are so full and comprehensive, that it is hardly possible for the committee to add anything to them. It may be well, however, to recapitulate briefly the results which have been obtained.

It is estimated that the yield of the Shawshine river, in a



season of extreme drought, provided suitable storage basins are established, would be about 20,500,000 gallons daily. In an ordinary year a supply of 24,000,000 or 25,000,000 might be obtained. The quality of the water compares favorably with the Sudbury, Charles and Mystic.

It will be necessary to raise the water by pumping for distribution in this city. The cost of works for an immediate daily supply of 8,000,000 gallons, planned so as to be readily enlarged from time to time, and eventually deliver the entire yield of the Shawshine, is estimated at \$2,623,775. The cost of delivering each million of gallons, on the basis of a delivery of 15,000,000 gallons daily, would be \$38.75; much higher than for the Charles and Sudbury river schemes, although a cheap class of works has been estimated upon. The plan involves the construction of a stand-pipe in place of a reservoir, the use of an open canal, and the laying of a 42-inch main over the West Boston Bridge. The stand-pipe system is an imperfect one; the use of an open canal is decidedly objectionable; and the bringing of the main supply across a wide and navigable river is attended with considerable risk.

In this estimate, as well as in the estimates which follow, no allowance is made for mill damages below the point of taking, or for interest during construction, or cost of negotiating loans. The mill damages on the Shawshine, at Ballardvale, and below, would be considerable.

The estimated cost of works built upon a different plan (such as has been proposed for the Sudbury river, see p. 18 City Engineer's Report), and capable of delivering in the city an average supply of twenty or twenty-five million gallons daily from the Shawshine, amounts to \$6,026,570. On the basis of a supply of 20,500,000 gallons daily, the cost for each million gallons delivered would be \$53.94. These works might be reduced to meet the wants of the immediate future so as to make the estimated expense \$4,480,000.

The estimated yield of the Concord river, without storage,



is 45,500,000 gallons daily. The engineer is of opinion that for the greater portion of the year the water from this source would prove unacceptable for domestic use, unless previously stored for some time. The estimated cost of works of a capacity to deliver 50,000,000 gallons daily, including a high level reservoir of a capacity of 120,000,000 gallons, is \$7,703,300. The cost of delivering each million of gallons is \$30.00. The estimated cost of works with a stand-pipe in place of a reservoir is \$6,880,000. The mill damages on the Concord would be very large.

Another scheme for procuring a supply of water from this source is described by the engineer, namely, turning the Concord into the lower basin of the Shawshine, by which the water from the former would be purified to some extent. The cost of delivering 50,000,000 gallons daily, upon this plan, is estimated at \$8,341,630, exclusive of heavy mill damages on both the Shawshine and Concord. Works of a smaller capacity ("with two engines, one compartment to the reservoir, one delivery main and the conduit brought from the Shawshine only") could be built for \$4,850,000.

The estimated cost of works for a supply of 50,000,000 gallons daily from the Merrimack river is \$13,224,200. The scheme embraces a pumping station, settling basins and filters at or near Lowell, and a conduit leading to the pumping engines at Winchester. The cost of each million gallons would be \$52.24. The cost of works proportioned to immediate use is \$7,800,000.

In regard to the quality of the water from the Merrimack, it is stated that at certain seasons of the year "it is very turbid, and the suspended matter does not readily subside, even when the water is at rest. The amount of matter held in suspension at such times is sufficient to render the water somewhat objectionable for domestic use, and entirely unfit for many manufacturing processes." The cost of suitable settling basins would be so large that filtration is regarded as the

only practicable method of freeing the water from its mechanical impurities. The mill damages on this river would also be very large.

On the order in relation to establishing a permanent connection between Farm pond and Lake Cochituate, and constructing a conduit from Lake Cochituate to Chestnut Hill reservoir, the City Engineer reports that it would be inexpedient, for reasons which are given on pp. 37-44. The estimated expense of bringing water from Sudbury river by that route is \$6,826,388.

On the order to ascertain the purity of the water of Charles river, at the point where it would be expedient to take it, the City Engineer submits the results of analyses made at different times during the past forty years, by well-known chemists. The able report by Prof. W. R. Nichols, made last year to the State Board of Health, on the present condition of certain rivers in Massachusetts, is printed in full in the Appendix. It is evident that the water of Charles river should be held in reservoirs for some time before it is used, and possibly it would require filtration unless important changes were made in the drainage area.

It appears from accurate surveys of the Mystic Water-shed (made under the authority of fourth order), that it covers an area of 27.75 square miles, being  $10\frac{1}{2}$  per cent. less than the area given by the Engineer of the Mystic Water Works, and 6.6 per cent. more than that given by Messrs. Kirkwood & Francis.

The information in relation to the damages which would accrue to the mill property on Charles and Sudbury rivers, by the use of the waters of those rivers (appended to this report), is furnished by Messrs. Warren & Adams of your committee, who, by practical experience, were peculiarly qualified to perform that duty.

For the convenience of members, the following condensed statement is presented, showing the estimated cost of the



various schemes before the City Council, for an additional supply of water, with the probable time required for the completion of the same, and the cost per million gallons.

*Sudbury river.* — Cost, \$5,150,000. (See page 58 City Doc. 29, 1873.) Time required, three full working seasons. Cost, per million gallons, \$21.17. This source will furnish a supply, in addition to the Cochituate, of 40,000,000 gallons daily in the dryest season.

*Mystic pond.* — Cost, \$1,408,546. (See page 18 City Doc. 134, 1873.) Time required, two full working seasons. Cost, per million gallons, \$40.00. This source will furnish for use in the city south of Charles river, a temporary supply of about seven or eight million gallons daily.

*Shawshine river.* — Scheme No. 1 (to furnish eight million gallons daily). Cost, \$2,623,775. (See page 15 City Engineer's Report, appended.) Time required, two full working seasons. Cost, per million gallons, for works of capacity to deliver 15,000,000 gallons daily, \$38.75.

*Shawshine river.* — Scheme No. 2 (to furnish 20,500,000 gallons daily). Cost, \$6,026,570. (See page 19 of Engineer's Report, appended.) Time required, three full working seasons. Cost, per million gallons, \$53.94.

*Concord river.* — Scheme No. 1. Cost, 7,703,300. (See page 29 City Engineer's Report, appended.) Time required, three full working seasons. Cost, per million gallons, \$30.00. This source will furnish 50,000,000 gallons daily.

*Concord river.* — Scheme No. 2. Cost, \$8,341,630. (See page 30 City Engineer's Report, appended.) Time required, three full working seasons. Cost, per million gallons, \$32.50. 50,000,000 gallons daily.

*Merrimack river.* — Scheme No. 1. Cost, \$13,065,000. (See page 34 City Engineer's Report, appended.) Time required, four full working seasons. Cost per million gallons \$53.64, by estimate of February 13, 1872. This source will furnish 50,000,000 gallons daily.



*Merrimack river.* — No 2. Cost, \$13,224,200. (See page 36 City Engineer's Report, appended.) Time required, four full working seasons. Cost per million gallons, \$52.24. 50,000,000 gallons daily.

*Charles river.* — Cost, \$3,150,000. Time required, two full working seasons. Cost per million gallons (works of capacity to deliver 50,000,000 gallons daily), without filtering, \$16.38; with filtering, \$30.00. (See pages 48, 49 and 50 City Engineer's Report, appended.) The mill damages on this river would be large. It would certainly be necessary to establish storage basins for the purification of the water, and there are no facilities for such basins on the line of the river within forty or fifty miles of this city.

If the Sudbury river scheme is adopted, there will be required during the next four or five years (in addition to the cost of the works) for mill damages, interest on construction account, new supply mains for newly annexed territory, and immediate additions to the high-service work, a sum not exceeding \$3,000,000.

The expenses connected with the taking of the Concord and Merrimack would largely exceed that amount; and for the Shawshine they would be somewhat less, — the mill damages being smaller.

The causes which led to the selection of Farm pond and Sudbury river as the most available sources from which to obtain an additional supply of pure water are set forth very fully and clearly in City Documents numbered 29 and 134 of the year 1873. Although the engineer was pressed to a decision in making the selection before complete surveys had been made, subsequent investigations have fully demonstrated the wisdom of the choice. If the question was entirely open, — if no steps whatever had been taken by the government in determining a new source of supply, — the committee would, with all the information now before them, unhesitatingly adopt the Sudbury river scheme as being, to use the

words of the mayor in his inaugural address, the surest, safest and most economical way of securing a permanent supply for the future. In the amount and quality of the water, the present and prospective freedom from pollution of the water-shed, the facilities for storage and control, the elevation (which is just sufficient to furnish the supply by gravitation and not so high as to require the payment of unnecessary mill damages), the shortness of the conduit line to Chestnut-hill reservoir, and the comparatively low cost of delivery as a permanent supply, this scheme possesses advantages over any of the others which have been examined.

The requisite legislation has been obtained, and the work has been actively entered upon. If any other scheme is adopted, additional legislation will be necessary, and a strong opposition will have to be encountered from other cities and towns and from private corporations; and the work which has been contracted for on the new conduit from Farm pond to Chestnut-hill reservoir must be abandoned and lost.

The adoption of the Cochituate scheme was violently opposed and at first rejected on the ground that the magnitude of the works was altogether beyond the future requirements of the city; and yet, in a period of less than thirty years, the wants of the city have outrun the extreme capacity of the source then selected. It must be kept constantly in view that the prosperity of our manufacturing interests, as well as the health and comfort of all our citizens, depends upon securing an abundant and unfailing supply of pure water. The prospective wants of the city are well presented in the following extract from the first report made last year:—

“It seems proper to take into consideration in this question the towns of West Roxbury, Brookline, Newton, Brighton and Hyde Park, all of which, as well as Boston, are situated upon an island formed by the harbor and the Charles and Neponset rivers and their connecting stream, Mother brook.



"The territory covered by Boston and the above towns is topographically one district, and hardly admits of subdivision when considered with reference to water supply and sewerage.

"The population of the entire district in 1870 was 287,787, and the rates of future increase applied to it will show a growth of 700,132 in fifty years, and a total population in 1920 of 987,919, or 1,000,000 of souls.

"One million of people will form a large city ; but when it is considered that Boston is the metropolis of New England, with its extensive territory and increasing manufacturing population, — that it is the radiating point for the whole system of New England railroads, — that it possesses a fine harbor, with which no other on the New England coast can compare in facilities for commerce, and that it is likely to become the port of at least a portion of the north-west, it does not appear unreasonable to suppose that it may grow to such a size within the estimated time.

"In looking then for a new source of supply the wants of at least one million of people should be kept in view, and in fixing upon the capacity of the works, those parts which cannot be enlarged or readily duplicated should be proportioned for an even greater number.

"The average daily consumption per inhabitant has varied during the past few years between wide limits, having been ninety to one hundred gallons as a maximum, and somewhat less than sixty as a minimum.

"As the new area to be provided for will undoubtedly contain a less proportion of manufacturing and shipping interests than that now supplied, and as there will probably be means devised at no distant day to check the great waste that has heretofore taken place, an allowance of sixty gallons for each person should and without much doubt will be ample.

"This allowance requires a total supply of 60,000,000



gallons daily, of which fully 12,000,000 will be furnished from Lake Cochituate, and about 48,000,000 must be obtained from new sources." [City Doc. 29, 1873.]

In conclusion, the committee desire to urge upon the City Council the great importance of acting upon this matter without any more delay than is absolutely necessary to a proper understanding of it. The reports of the City Engineer and his able assistants, and of Messrs. Kirkwood and Francis, furnish sufficient information to enable every member of the government to act intelligently upon the question.

Respectfully submitted,

S. B. STEBBINS,  
JOHN T. CLARK,  
ALANSON BIGELOW,  
FREDERICK PEASE,  
EBENEZER ADAMS,  
WILLIAM H. KENT,  
FRANCIS HUNNEWELL,  
*Majority of Committee.*

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## MINORITY REPORT.

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The undersigned regrets that he cannot agree with the majority report. His reasons he will briefly state.

So far as it concerns the order of the committee to consider the expediency of constructing a conduit from Lake Cochituate to Chestnut Hill reservoir, etc., it is evident that the subject has been evaded as much as possible. The undersigned, finding that the meaning of the order had been somewhat misconstrued, requested the City Engineer to make an estimate of the cost of a conduit of about the size

of the present one ; that it was not the intent nor spirit of the order requiring an estimate of a conduit from Farm pond to Lake Cochituate, as none is needed, any more than it would be in the bed of the Sudbury river ; that the conduit which was considered by the engineer was of a capacity double the size needed for the whole Sudbury river.

After making several requests of the City Engineer to report the cost of a conduit of the proper capacity, he reluctantly concluded to do so ; but refused to allow it to go into print with the report of the committee.

The undersigned is opposed to the line of conduit proposed by the Water Board, from Farm pond to the reservoir without entering the lake, for many reasons. First, that it involves an expenditure of about \$10,500,000, including damages ; will take four or five years to complete it ready for use, and would allow no chance for the aeration and purification of the water.

There can be no reasonable objection to using the lake at nearly its maximum height of water. There is no necessity of using the lake as a storage basin, for we will have 1,884 acres of storage basins at the head of the Sudbury. There will ordinarily be nearly if not quite as much fall to the mile on this route as on the other.

An extra strong conduit, of an area of twenty-eight square feet, and capable of discharging 35,000,000 gallons per day, costing but a little over \$2,000,000, according to the engineer's estimate, and including all the land and mill damages, will not exceed \$4,500,000. The above conduit can be built by the side and parallel with the Cochituate conduit, without any difficulty, and both can be bridged over Charles river, instead of using siphons, which is included in the above estimated cost.

The new conduit, together with the old one repaired and improved at Charles river crossing, will convey 55,000,000 gallons per day, which would be an ample supply for 40

years. By that time the towns along the line of the Sudbury will most likely need the remainder of the water in the river, which they will have a right to take. But if, at that time, it should prove otherwise, the old conduit could be rebuilt, and enlarged to suit the requirements of the times. The conduit recommended by the minority can be built in one season. The other will take four or five years.

Boston cannot, nor will it, wait four or five years for the completion of this immense undertaking. Therefore a conduit will have to be built on the Cochituate line very soon, whether the other is built or not.

These facts must be apparent to the Water Board. Why not build this first, and not wait for the passage of the order for the more expensive one?

We cannot get rid of building another conduit for the Cochituate, unless we give up and abandon the lake, and it is hoped that the people will never submit to that.

The present conduit has been condemned many times, and, of course, if it cannot stand, it must be the intention to build another by its side, and why not do this first, and stop to breathe before we plunge the city deeper into debt on this needless expenditure?

Respectfully submitted,

ALONZO WARREN.





# REPORT OF SUB-COMMITTEE

ON THE NUMBER AND CHARACTER OF MILLS AND AMOUNT  
OF WATER USED, ON THE CHARLES, SUDBURY, AND  
OTHER RIVERS.

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CITY OF BOSTON.

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IN COMMITTEE ON WATER, April 17, 1874.

The sub-committee of the Joint Standing Committee on the Water Department, to whom was referred the order to ascertain the number of mills and the average amount of water required daily by each on Charles and Sudbury rivers respectively, having attended to that duty, would respectfully submit the following report : —

The sub-committee have visited all the mills on the Charles river, Mother brook and Neponset, Sudbury, Concord, and Merrimac rivers, which would be affected in any way by obtaining from the Charles or Sudbury rivers a supply of water for this city. The principal results of their investigations are set forth in the following tables, which show (in all cases where the information was attainable) the number of mills, the number of wheels in each, the size and kind of wheels, the amount of water used, the fall of water, and the power obtained.

## SUDBURY AND CONCORD RIVERS.

| KIND OF GOODS    | MANUFACTURED. | NAME<br>OF PROPRIETORS. | HEAD OF WATER. | NO. OF WHEELS. | SIZE OF WHEELS. | KIND OF WHEELS.      | HORSE POWER. | AMOUNT<br>OF WATER. | LOCATION.             | GENERAL REMARKS.                      |
|------------------|---------------|-------------------------|----------------|----------------|-----------------|----------------------|--------------|---------------------|-----------------------|---------------------------------------|
| Emery Works      |               | Charles Alden . . .     | 9 feet .       | 2              | 4½ feet         | Warren . . . . .     | 72           | . . . . .           | Ashland . . . . .     | . . . . .                             |
| Grist Mill . . . |               | Cutter . . . . .        | 7 " .          | 1              | 6 "             | " . . . . .          | 42           | . . . . .           | " . . . . .           | . . . . .                             |
| "                |               | Simpson . . . . .       | 3½ "           | . . .          | . . . . .       | . . . . .            | . . .        | . . . . .           | Saxonsville . . . . . | No wheels. Works burned<br>down.      |
| Carpet Works     |               | " . . . . .             | 23 "           | 1              | 7 "             | Boyd . . . . .       | . . .        | . . . . .           | " . . . . .           | . . . . .                             |
| "                |               | " . . . . .             | 23 "           | 1              | 5 "             | Warren . . . . .     | 325          | . . . . .           | " . . . . .           | Power ascertained by indi-<br>cation. |
| "                |               | " . . . . .             | 23 "           | 1              | Small .         | No name . . . . .    | . . .        | . . . . .           | " . . . . .           | . . . . .                             |
| Woollen . . .    |               | Faulkner . . . . .      | 11 "           | 1              | 5½ feet         | Lincoln . . . . .    | 50           | . . . . .           | Billerica . . . . .   | . . . . .                             |
| "                |               | Talbot . . . . .        | 11 "           | 1              | 7½ "            | Swain . . . . .      | 100          | . . . . .           | " . . . . .           | . . . . .                             |
| "                |               | " . . . . .             | 11 "           | 1              | 5 "             | Fall River . . . . . |              | . . . . .           |                       | . . . . .                             |
| Dye Wood . .     |               | " . . . . .             | 11 "           | 3              | . . . . .       | Blake . . . . .      | . . .        | . . . . .           | " . . . . .           | . . . . .                             |
| "                |               | " . . . . .             | 11 "           | 3              | . . . . .       | Whitney . . . . .    | . . .        | . . . . .           | " . . . . .           | . . . . .                             |
| Variety Mfg. Co. |               | Wamesit Power Co.       | 24 to 26 ft.   | 2              | 4 "             | Warren . . . . .     | 222          | . . . . .           | Lowell . . . . .      | Claim 26 feet head.                   |
| "                |               | " . . . . .             | "              | 3              | . . . . .       | Houston . . . . .    | . . .        | . . . . .           | " . . . . .           | . . . . .                             |



| Variety Mfg Co.        | Wameit Power Co.        | 24 to 26 ft. | 1  | Swain |  |     | Lowell             |                                           |
|------------------------|-------------------------|--------------|----|-------|--|-----|--------------------|-------------------------------------------|
| Bolts . . . . .        | "American" . . . . .    | 20 feet .    | 1  | 28 "  |  | 75  | 1,620 ft. per m.   | Owners claim 75 horse power, by purchase. |
| Woollen . . . . .      | Chase . . . . .         | 23 "         | 1  | 4 "   |  | 80  |                    |                                           |
| " . . . . .            | Faulkner . . . . .      | 23 "         | 1  | 2½ "  |  | 60  | 1,500 ft. per m.   | Owners claim 60 horse power, by purchase. |
| " . . . . .            | Stirling . . . . .      | 24 "         | 1  | 2½ "  |  | 75  |                    |                                           |
| " . . . . .            | Belvidere . . . . .     | 24 "         | 1  | 4 "   |  |     | 1,620 ft. per m.   |                                           |
| " . . . . .            | " . . . . .             | 10 "         | 1  |       |  |     |                    | Uses surplus water only.                  |
| Bleachery . . . . .    | Lowell . . . . .        | 24 "         | 1  | 4 "   |  | 75  | 2,160 ft. per m.   | Claims 75 horse power, by purchase.       |
| Grist Mill . . . . .   | Woods . . . . .         | 25 "         | 1  |       |  | 25  |                    | 11 hours per day.                         |
| Wool & Paper . . . . . | " . . . . .             | 8 "          | 5  |       |  | 100 |                    | Own power both sides.                     |
| Woollen . . . . .      | Middlesex . . . . .     | 10 "         | 3  |       |  |     |                    |                                           |
| " . . . . .            | Essex Power Co. . . . . | 30 "         | 67 |       |  |     | 210,000 ft. per m. | Lawrence . . . . .                        |

## CHARLES RIVER.

| KIND OF GOODS MANUFACTURED.   | NAME OF PROPRIETORS.  | HEAD OF WATER.   | NO. OF WHEELS. | SIZE OF WHEELS.   | KIND OF WHEELS.      | HORSE POWER. | AMOUNT OF WATER. | LOCATION.                                                                              | GENERAL REMARKS. |
|-------------------------------|-----------------------|------------------|----------------|-------------------|----------------------|--------------|------------------|----------------------------------------------------------------------------------------|------------------|
| Flax & Leather Manuf. . . . . | Fisk & Clark . . . .  | 9 feet . . . . . | 3              | 3½ feet . . . . . | " Russell" . . . . . | . . . . .    | . . . . .        | South Natick . . . . .                                                                 | . . . . .        |
| Grist Mill . . . . .          | " . . . . .           | 6½ " . . . . .   | 1              | 6 " . . . . .     | Ryder . . . . .      | . . . . .    | . . . . .        | " . . . . .                                                                            | . . . . .        |
| Waban Mills . . . . .         | Wm. Hill & Son . . .  | 9 " . . . . .    | 2              | 4 " . . . . .     | Blake . . . . .      | . . . . .    | . . . . .        | Charles River Vil. . . . .                                                             | . . . . .        |
| " . . . . .                   | " . . . . .           | 9 " . . . . .    | 1              | 45 in. . . . .    | Houston . . . . .    | . . . . .    | . . . . .        | " . . . . .                                                                            | . . . . .        |
| " . . . . .                   | " . . . . .           | 9 " . . . . .    | 1              | 36 " . . . . .    | Blake . . . . .      | . . . . .    | . . . . .        | " . . . . .                                                                            | . . . . .        |
| " . . . . .                   | " . . . . .           | 9 " . . . . .    | 1              | 5 feet . . . . .  | Warren . . . . .     | . . . . .    | . . . . .        | " . . . . .                                                                            | . . . . .        |
| " . . . . .                   | " . . . . .           | 9 " . . . . .    | 1              | 30 in. . . . .    | Blake . . . . .      | . . . . .    | . . . . .        | " . . . . .                                                                            | . . . . .        |
| Prints . . . . .              | Newton Mills . . . .  | 14 " . . . . .   | 1              | 56 " . . . . .    | " Lefel" . . . . .   | 120.5        | 5,481 ft. perm.  | Newton U. Falls. }<br>The remainder of water runs<br>over the dam 9,835 cub.<br>ft. m. | . . . . .        |
| " . . . . .                   | " . . . . .           | 14 " . . . . .   | 1              | 66 " . . . . .    | " . . . . .          | 183          | 7,800 "          | " . . . . .                                                                            | . . . . .        |
| Iron Works . . . . .          | N. Iron Works . . . . | 10½ " . . . . .  | 2              | 3 feet . . . . .  | Blake . . . . .      | . . . . .    | . . . . .        | " . . . . .                                                                            | . . . . .        |
| " . . . . .                   | " . . . . .           | 10½ " . . . . .  | 3              | 6 " . . . . .     | " . . . . .          | . . . . .    | . . . . .        | " . . . . .                                                                            | . . . . .        |
| Machinery . . . . .           | Eaton Moulton . . . . | 10 " . . . . .   | 1              | 12 " . . . . .    | Breast . . . . .     | . . . . .    | . . . . .        | " . . . . .                                                                            | . . . . .        |
| Paper . . . . .               | Rice Mills . . . . .  | 10 " . . . . .   | 2              | 4 " . . . . .     | Blake . . . . .      | . . . . .    | . . . . .        | Newton L. Falls. . . . .                                                               | . . . . .        |

|                           |                         |             |           |           |                    |           |           |                     |                           |
|---------------------------|-------------------------|-------------|-----------|-----------|--------------------|-----------|-----------|---------------------|---------------------------|
| Paper . . . . .           | Rice Mills No. 2 . . .  | 10 feet . . | 1         | 4½ feet   | Russell . . . . .  | . . . . . | . . . . . | Newton L. Falls . . | . . . . .                 |
| " . . . . .               | Rice Mills . . . . .    | 10 " . .    | 1         | 4 "       | Blake . . . . .    | . . . . . | . . . . . | " . . . . .         | . . . . .                 |
| Hosiery . . . . .         | Dudley Hosiery Co. . .  | 8 " . .     | 1         | 4 "       | " . . . . .        | . . . . . | . . . . . | " . . . . .         | . . . . .                 |
| " . . . . .               | " . . . . .             | 8 " . .     | 1         | 3½ "      | Warren . . . . .   | 16½       | . . . . . | " . . . . .         | . . . . .                 |
| Paper . . . . .           | W. & S. Cordingley . .  | 16 " . .    | 1         | 18 "      | Breast . . . . .   | . . . . . | . . . . . | " . . . . .         | Buckets, 18 ft. long.     |
| " . . . . .               | L. Crehore . . . . .    | 16 " . .    | 1         | 3½ "      | Blake . . . . .    | . . . . . | . . . . . | " . . . . .         | . . . . .                 |
| " . . . . .               | " . . . . .             | 16 " . .    | 1         | 3 "       | " . . . . .        | . . . . . | . . . . . | " . . . . .         | . . . . .                 |
| " . . . . .               | " . . . . .             | 16 " . .    | 1         | 16 "      | Breast . . . . .   | . . . . . | . . . . . | " . . . . .         | . . . . .                 |
| " . . . . .               | Wiswold . . . . .       | 6½ " . .    | 2         | 4½ "      | Sanborn . . . . .  | . . . . . | . . . . . | " . . . . .         | . . . . .                 |
| Shoddy . . . . .          | Francis . . . . .       | 6½ " . .    | 1         | . . . . . | . . . . .          | 25        | . . . . . | " . . . . .         | . . . . .                 |
| Cotton Goods . . . . .    | Boston Manuf'g Co. . .  | 12 " . .    | 6         | . . . . . | Warren & Swain . . | 618       | . . . . . | Waltham . . . . .   | . . . . .                 |
| Bleaching . . . . .       | Waltham Bleachery . .   | 4½ " . .    | . . . . . | . . . . . | . . . . .          | . . . . . | . . . . . | " . . . . .         | Uses water for bleaching. |
| Woollen . . . . .         | Ætna Mills . . . . .    | 4½ " . .    | 3         | . . . . . | Boyden . . . . .   | 95        | . . . . . | " . . . . .         | Uses water for washing.   |
| Paper . . . . .           | Hollingsworth . . . . . | 5½ " . .    | 1         | 8 "       | Blake . . . . .    | . . . . . | . . . . . | Watertown . . . . . | . . . . .                 |
| " . . . . .               | " . . . . .             | 5½ " . .    | 1         | 6 "       | Warren . . . . .   | 40        | . . . . . | " . . . . .         | . . . . .                 |
| " . . . . .               | " . . . . .             | 5½ " . .    | 1         | 4½ "      | " . . . . .        | 16        | . . . . . | " . . . . .         | . . . . .                 |
| " . . . . .               | " . . . . .             | 5½ " . .    | 1         | . . . . . | . . . . .          | . . . . . | . . . . . | " . . . . .         | Small wheel.              |
| Grist Mill . . . . .      | Perkins . . . . .       | 5 " . .     | 1         | 9 "       | Ryder . . . . .    | 60        | . . . . . | " . . . . .         | . . . . .                 |
| Sash and Blinds . . . . . | Sanger . . . . .        | 5 " . .     | 1         | 5 "       | " . . . . .        | . . . . . | . . . . . | " . . . . .         | Uses surplus water.       |
| Castings, &c. . . . .     | Pratt & Co. . . . .     | 5 " . .     | 1         | 5 "       | " . . . . .        | . . . . . | . . . . . | " . . . . .         | "                         |

## MOTHER BROOK AND NEPONSET RIVER.

| KIND OF GOODS MANUFACTURED. | NAME OF PROPRIETORS. | HEAD OF WATER. | NO. OF WHEELS. | SIZE OF WHEELS.     | KIND OF WHEELS.    | HORSE POWER. | AMOUNT OF WATER.    | LOCATION.            | GENERAL REMARKS.                            |
|-----------------------------|----------------------|----------------|----------------|---------------------|--------------------|--------------|---------------------|----------------------|---------------------------------------------|
| Wool Washing                | Merchants' Mfg. Co.  | 6 feet .       | ..             | .....               | .....              | .....        | .....               | Mill Village . . . } | First mill privilege on M. Brook.           |
| Woollen Cloth               | "                    | 9 "            | 2              | 3 1-12 ft. Hathaway | .....              | .....        | .....               | " " }                | Second mill privilege on M. Brook.          |
| "                           | "                    | 9 "            | 1              | 3 1-12 ft. Tyler    | .....              | .....        | .....               | " " }                | Second mill privilege on M. Brook.          |
| Grist & Saw Mill            | "                    | 10 "           | ..             | .....               | .....              | .....        | .....               | " " }                | Third mill privilege on M. Brook.           |
| Woollen . . .               | "                    | 10 "           | ..             | .....               | Hunt, Wait & Flint | .....        | .....               | " " }                | Fourth mill privilege on M. Brook.          |
| Cotton Goods .              | Smithfield Mfg. Co.  | 7 1/2 "        | 2              | 4 1/2 ft. Lefel     | .....              | 100          | .....               | Readville . . . }    | One wheel will take all the water.          |
| Woollen . . .               | Hyde Pk W'ol'n Co.   | .....          | ..             | .....               | .....              | ..           | 1,000 galls. p'r m. | Hyde Park . . . }    | Use water for washing only.                 |
| Paper . . . .               | Hollingsworth        | 8 1/2 "        | 2              | ..                  | Boydell            | 80           | .....               | Mattapan . . . }     | Junction of Muddy Brook and Neponset River. |
| " . . . .                   | "                    | 8 1/2 "        | 2              | Small .             | .....              | 16           | .....               | " " }                | .....                                       |
| " . . . .                   | "                    | 7 1/2 "        | 4              | .....               | .....              | 80           | .....               | " " }                | .....                                       |
| " . . . .                   | "                    | 7 1/2 "        | 1              | .....               | .....              | .....        | .....               | " " }                | .....                                       |



| Paper . . . . .             | Hollingsworth . .  | 9 feet . | 3 | 7 ft.     | Boyd  | 100       | . . . . . | Mattapan . . . . . | Water over weir 14,064.9-10<br>cub. ft. per m. |
|-----------------------------|--------------------|----------|---|-----------|-------|-----------|-----------|--------------------|------------------------------------------------|
| Chocolate Mill              | Baker's . . . . .  | 6 "      | 4 | . . . . . | Ryder | . . . . . | . . . . . | Milton             | . . . . .                                      |
| "                           | Pierce's . . . . . | 6 "      | 1 | . . . . . | "     | . . . . . | . . . . . | "                  | . . . . .                                      |
| Chocolate and<br>Grist Mill | Webb's . . . . .   | 6 "      | 2 | . . . . . | "     | . . . . . | . . . . . | "                  | . . . . .                                      |
| Woollen . . . . .           | . . . . .          | 6 "      | 2 | . . . . . | "     | . . . . . | . . . . . | "                  | . . . . .                                      |

The information presented in the foregoing tables was obtained in most cases from the mill-owners, superintendents, or employés. In regard to the measurements of water at the weirs, it should be stated that those were taken in the presence of your committee, and may be considered as showing substantially the condition of the water at that time.

There is great difficulty in making anything like an intelligent estimate of the damages which would result to the mill privileges, by taking a supply of water from the above-named sources; and, in furnishing the foregoing statement, your committee have endeavored to cover all the facts so far as they were ascertainable, which would be of value in enabling the individual members of the government to judge, as well as the members of the committee, as to the amount of damage likely to accrue from the action of the city.

It has occurred to your committee that the water power at Saxonville would serve as a guide in ascertaining the amount of water running at that point of the Sudbury river. The proprietors of the Saxonville mills claim that they have equal to three hundred and twenty-five horse power during nine months in the year, — that fact having been ascertained from tests made by steam power. At the time the committee visited those mills (March 10th, 1874), the entire works were run by the water power alone.

The agent of the Wamesit Power Co., of Lowell, was very cautious about giving information in regard to the amount of water used by that company, and referred us to Hon. Benjamin F. Butler for any information we desired on that subject.

Respectfully submitted,

ALONZO WARREN,  
EBENEZER ADAMS.

# REPORT OF CITY ENGINEER.

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OFFICE OF THE CITY ENGINEER,  
CITY HALL, BOSTON, March 31, 1874.

ALDERMAN S. B. STEBBINS, *Chairman Joint Standing Committee on Water*: —

SIR: The following orders of the City Council were referred to me by your committee during the past month, with the request that I should make the required investigations and report: —

"IN COMMON COUNCIL, Jan. 29, 1874.

"*Ordered*, That the Joint Standing Committee on Water consider and report upon the possibility and expense of adding to the waters of the Mystic pond a supply sufficient for the use of the city, by connecting said pond with Shawshine, Concord and Merrimack rivers, or either of them, by the use of the bed of the Middlesex Canal or otherwise."

"IN COMMON COUNCIL, Jan. 29, 1874.

"*Ordered*, That the Committee on Water be requested to consider the expediency of making a permanent water-connection between Farm pond and Lake Cochituate, build a conduit from Lake Cochituate to Chestnut Hill Reservoir — said conduit to be bridged over Charles river instead of siphons in said river, and report an estimated cost of same."

"IN COMMON COUNCIL, Feb. 16, 1874.

"*Ordered*, That the Joint Standing Committee on Water ascertain, by analysis or otherwise, the purity of the water of Charles river at the most expedient point of taking the same for the use of the city of Boston, the expense to be charged to the appropriation for additional water supply."

In compliance with your request I have had made approximate surveys and estimates, and now respectfully submit the following report:—

## THE SHAWSHINE.

### QUANTITY.

The Shawshine rises in Lexington and Bedford, and flows in a north-easterly direction through Andover to the Merrimack river, which it enters below Lawrence.

The drainage area or water-shed of that portion of it which lies above the old Middlesex Canal, as computed from the County Map, is 34 square miles. Although no survey of the boundary line has been made, the area above given cannot be greatly in error, as it has been determined quite carefully by the method adopted by Messrs. Kirkwood and Francis for the Mystic basin. First the accuracy and scale of the map were tested, and, if necessary, corrections made, by measuring upon the ground distances taken from it; next the boundary line was determined by a careful examination of the district, and laid down on the map, by noting where it crossed roads or other landmarks. The enclosed area was then computed and checked.

The water-surfaces, including those of the proposed storage basins, cover an area of somewhat less than three square miles. As the yearly evaporation from a water-surface is greater than the amount of rain that falls upon it, its area



must be deducted from that of the water-shed, in determining the capacity of a source of supply. We have then an effective water-shed of 31 square miles for that portion of the Shawshine which is here considered.

In the year of extreme drought, experience has proven that about 12 inches of rainfall enter the brooks and streams, and that a storage capacity equal to 120 days' supply is required to equalize the flow of such a year and render the total amount available.\*

Twelve inches of rain upon 31 square miles will give a daily flow of 17,711,000 gallons.

If the capacity of the storage basins that may be built is equal to 120 days' supply only, or 2,125,320,000 gallons, then it is not safe to reckon upon a greater supply for the dry year than that given by the portion of rainfall collectable in such a year, or 12 inches.

Surveys have been made to determine the storage facilities of the valley, and it is found that an available capacity of 3,158,000,000 gallons may be readily obtained by the construction of three dams; this will admit of carrying over from the average year for use in the dry year,  $3,158,000,000 - 2,125,000,000 = 1,033,000,000$  gallons, which will furnish a daily supply of  $\frac{1,033,000,000}{365} = 2,830,000$  gallons in addition to the available rainfall of the latter year.

It will therefore be safe to estimate the least daily yield of the Shawshine above the Middlesex Canal, with its proposed storage basins, at  $17,711,000 + 2,830,000 = 20,541,000$ , or say 20,500,000 gallons, equal to 14 inches of rainfall for the year.

A somewhat greater result than this is obtained by applying the method adopted by Mr. Kirkwood and Mr. Francis

\* Without storage the available yield would be reduced to the *summer* flow of the stream, which, in a dry year, may be taken at 200,000 gallons daily per square mile of water-shed, or a little over 6,000,000, for 31 square miles. In a very dry summer the flow is still less.

in estimating the yield of the Mystic basin during a season of drought.

They assume that 15 inches of rain may be collected in such a year, and show that storage capacity equal to about 180 days' supply is needed to equalize the flow and render the whole available. Fifteen inches in depth upon 31 square miles will yield a daily supply of 22,000,000 gallons, for which there is required a storage capacity of 2,860,000,000 gallons. In the case of the Shawshine we have an excess of storage-room of 300,000,000 gallons, which will furnish a daily supply of 820,000 gallons for a year; therefore the minimum daily supply, computed by this method, will be  $22,000,000 + 820,000 = 22,820,000$  gallons.

Within certain limits there exists some uncertainty or difference of opinion as to what data shall be used in solving questions relating to the supply for the dryest year; the circumstances under which these gentlemen were called upon to make the estimate for the Mystic basin rendered it natural and proper for them to select the data from that limit of the range of uncertainty which would produce the greatest results, giving the Mystic the benefit of the doubt. They were further warranted in this course, because what is here termed the dryest year occurs only at long intervals, say twenty years or more, and the real question behind, but nevertheless pervading those presented for their consideration, was, will the Mystic afford a supply sufficient to justify the expenditure necessary to make its surplus water (beyond that required for the district north of the Charles) available for a *temporary* supply to Boston?

In estimating for a *permanent* supply, I deem it proper to take the data from the other limit, following in this respect the method adopted in estimating for the Sudbury and most of the other sources considered in the report of 1873 (City Doc. No. 29), and among others, for the following reason.

The Cochituate tables show that in 1871, with a rainfall

of  $45\frac{3}{100}$  inches, only  $14\frac{6}{100}$  inches found their way to the lake, the rest of the fall having been lost by evaporation and absorption.

The rain tables published in the report of the Water Board for 1871 (City Doc. No. 78, 1873) show that frequently the yearly rainfall is considerably less than  $45\frac{3}{100}$  inches.

Thus, in 1849, the fall at Lake Cochituate was  $34\frac{6}{100}$  inches, in 1852,  $38\frac{5}{100}$  inches, in 1855,  $39\frac{5}{100}$  inches, in 1860,  $38\frac{2}{100}$  inches, in 1864,  $36\frac{8}{100}$  inches; the fall in 1846 at Lowell was  $28\frac{3}{100}$  inches only, and since 1842 there have been nine years when the fall was less than 40 inches; at Boston in 1846 the fall was  $29\frac{9}{100}$  inches, and since 1842 there have been three years when it was less than 40 inches; at Cambridge the fall in 1846 was  $30\frac{3}{100}$  inches, and since 1842 there have been two years when it was less than 40 inches, and four years when it was between 40 and 41 inches.

Should any of these low rainfalls occur with conditions favorable for a high ratio of evaporation from the ground surface, the figures for 1871 show us that, at such times, the amount of water reaching the streams would not much, if at all, exceed a depth of 12 inches upon the area of the watershed.

Gaugings taken at the outlet of Long pond or Lake Cochituate, from June 27, 1837, to July 27, 1838, show that only  $11\frac{7}{10}$  inches of the rainfall passed through the lake during that year.

It would be unwise, therefore, in estimating for a permanent supply, to place the yield of the Shawshine in a season of extreme drought at more than  $20\frac{1}{2}$  million gallons daily.

The *average daily flow* of this river at the canal for a series of years must be about 31,000,000 gallons, being in some years as great as 40 or 45 millions, and in others as little as 18 or 20 millions; of the *average* flow a large fraction must be wasted during freshets and the melting of the snows in

spring, and allowed to pass on to the ocean by its natural channel, but undoubtedly during an ordinary year a supply of 24 or 25 millions may be obtained. In stating the available capacity, however, the yield of the year of drought should be given, as that yield determines the real value of the source. (See Appendix I.)

I would refer you to the report upon the Sudbury (City Doc. No. 29, 1873, pages 9-28), for a different treatment and more in detail, of this question of available capacity of a water source as depending upon the least rainfall and amount of storage room that can be secured.

#### QUALITY.

Judging from the character of the country drained by this river, the water must be pure and well suited for a domestic supply.

The district is sparsely populated, and very little manufacturing of an objectionable kind is carried on within it.

Like all rivers flowing through meadow lands, the Shawshine is liable to become highly colored at certain seasons of the year, and at the time the surveys were made (in February) the water had a decidedly marshy or earthy taste, but probably both the color and taste would be lost during storage in capacious basins. As a rule, the waters of no river should be introduced for a domestic supply until they have undergone the processes of subsidence and exposure to the air in basins or otherwise, and in comparing such waters as they are taken from the natural flow of the river, with those already in use in various cities, it should be borne in mind that they are, as it were, in their crude state, and are to undergo an imperfect, but nevertheless important, process of preparation before being delivered for use.

The following is an analysis, by Messrs. Merriek & Gray, of a sample of water taken Feb. 20th from the Shawshine,



at the point where it passes under the Boston and Lowell railroad.

"*Sample 3.* This was yellowish, with a very faint odor, and some flocculent deposit.

"The unconcentrated water gave a prompt reaction with the Nessler test.

"Analysis gave, —

|                            |       |                         |
|----------------------------|-------|-------------------------|
| Suspended matter . . .     | 0.19  | grs. to 1 U. S. gallon. |
| Organic and volatile . . . | 1.19  | " " "                   |
| Inorganic . . . . .        | 1.85  | " " "                   |
|                            | <hr/> |                         |
|                            | 3.23  |                         |

"The inorganic matter contained, —

|                                                        |       |       |
|--------------------------------------------------------|-------|-------|
| Silica, alumina, sesquioxide<br>of iron, etc., . . . . | 0.443 | " " " |
| Chlorine, as chloride of<br>sodium . . . . .           | 0.378 | " " " |
| Sulphate of lime . . .                                 | 0.705 | " " " |
| Albuminoid ammonia . .                                 | .017  | " " " |
| Ammonia . . . . .                                      | .0036 | " " " |

This analysis will compare favorably with those of other river-waters, as, for instance, the Sudbury, Charles and Mystic.

In the report of the Cochituate Water Board (City Doc. No. 134, 1874, pages xiv. to xx.) will be found some remarks upon the effect of storage.

#### SCHEMES OF WORKS, AND ESTIMATES OF COST.

As the elevation of the water-surface of the lowest proposed basin is 99 feet above mean high tide, the water must be pumped for distribution in the city.

In the first scheme of works for which estimates will be given, it is proposed to turn the Shawshine into the upper

reach of the Abajonna, and use the latter river as the course for conveying the water to Mystic lake.

If the pumping capacity and size of the force and delivery mains of the Mystic works are sufficient to provide a supply to Boston for a few years, then the present outlay may be limited to the cost of storage basins, some changes in the street pipes, and the work above mentioned. It is therefore necessary, before making an estimate, to determine what additional supply Boston will require in the immediate future, and to ascertain what may be called the *safe working capacity*, in distinction from the *total capacity*, of the Mystic pumps and mains.

Let the capacity of the Cochituate works be placed at 16,000,000 gallons daily, taking the risk of a dry year occurring during the next four or five years. The probable daily yield of the Cochituate, in the dryest year, has been estimated to be about 12,000,000 gallons. In 1871 it was a little over 13,000,000 in 1866 it was about 15,000,000. In 1864, for six months of the year, the water in the lake was kept considerably above high-water mark, and the storage capacity was thereby considerably increased. As we are now compelled to manage the height of water, the supply for that year would have been about 16,000,000, and the lake would have been exhausted at the end of the year.

The average daily consumption last year was nearly 18,000,000. We must anticipate a considerably increased consumption for this year. The natural yearly increase, by increase of water-takers and for trade use, may be placed at five or six per cent.; if we assume it at 365,000,000 gallons, equal to 1,000,000 daily, we shall be placing it at a low limit; then by natural growth the increase of daily consumption in five years would amount to 5,000,000 gallons. West Roxbury and Brighton must soon be supplied. In 1870 they had a population of

13,650; five years hence, or at the end of 1878, they will have a population not far from 18,000; which, at 60 gallons per head, will require a supply of 1,000,000 gallons per day. Then, by a low estimate, it is found that the daily consumption in that part of Boston which lies to the south of the Charles, will be, in 1878, about 24,000,000; unless, indeed, the Water Board shall be given ample power to prevent waste and extravagant use.

The Cochituate, it is assumed, will yield 16,000,000; an additional supply of at least 8,000,000 must therefore be soon provided; and it would be short-sighted policy to make any large expenditures to obtain a less supply, except for very temporary purposes, and in the face of a pressing emergency, when time might be of more importance than cost. In fact, the works for a supply of 8,000,000 could hardly be completed before an increase in their capacity must be begun.

The Mystic works are provided with three pumping engines, two capable of pumping 5,000,000, and one 8,000,000 in 24 hours. The total pumping capacity is, therefore, 18,000,000 per day.

Experience has proven, what should be evident upon reflection, that to insure a supply for each and every day of a series of years, some means must be provided that will admit of throwing a part of the machinery out of use, for a longer or shorter time, for repairs, renewals, etc.; and, in case of a serious accident, this time may be from one to two months.

With a large distributing reservoir, one holding a supply for several days or weeks, it might, perhaps, be considered justifiable to allow the consumption to reach nearly the full capacity of the pumps before providing an increase of power; but this is not the practice. There should always be a surplus of power, that at least one engine may be thrown out of use at any and all times.

The total capacity of the Charlestown reservoir is given in the report for 1865 as 26,244,415 U. S. gallons, or only three days' supply for the present consumption of the cities drawing from it. In the actual management of the works, it is considered essential to keep the water always at or near high-water mark, as the reservoir cannot be drawn upon to any great extent without serious inconvenience to people residing upon the higher lands of the cities that receive the supply. It will be seen that the capacity is not sufficient to warrant the omission of an extra engine.

If one of the 5,000,000 gallon engines is disabled, the pumping capacity will be 13,000,000 per day, and in case the 8,000,000 engine is idle, the capacity will be 10,000,000. The safe working capacity would ordinarily be stated at 10,000,000; but even supposing it can be taken at 13,000,000, it will be found that it is but a little in excess of the varying requirements of the present consumption.

This is well illustrated by the following extract from the report of the Mystic Water Board for 1872, page 4: "The large increase in the consumption of water demonstrates the fact that the Board acted wisely and none too promptly in recommending the City Council to authorize the construction of the new thirty, twenty and sixteen inch pipes for supply and distribution, and also the third pumping-engine, as it would be utterly impossible to furnish a supply at this time without them; the full capacity of the new pump and nearly that of one of the old ones being necessary to keep up the supply.

"After the new engine was in successful operation, an examination of engine No. 1 and the check valves was had, and they were both found to be in such condition that we should have been unable to use either many days longer, which would have deprived the city of water for some days at least. . . ."



During the cold weather, when water is allowed to run constantly to prevent freezing, the consumption, for days at a time, has been 11 or 12,000,000 gallons, and it has been necessary to pump this amount to keep up the supply.

The Brooklyn, N. Y., works have a distributing reservoir holding 160,000,000 gallons, with two engines, each of 15,000,000 gallons' capacity, and when the consumption was somewhat less than 15,000,000 daily, an accident to one engine, while the other was dismantled for cleaning and repairs, nearly deprived the city of water. The reservoir was drawn down to but a few hours' supply before either engine could be put in working order. A third engine has since been added.

The St. Louis works have two supply engines, each of a capacity of 16,500,000 gallons; when the consumption reached this amount it was considered necessary to add a third engine, and one of a capacity of 24,000,000 is now under construction. This work has a distributing reservoir holding about 56,000,000 gallons.

It is evident that the pumping capacity of the Mystic works is not sufficient for furnishing Boston with anything more than a very temporary supply.

There is but one pumping main (30 inches diameter), and this is now used to nearly its full capacity.

There are two distributing mains, one 24 inches and the other 30 inches in diameter, which, with an average velocity of flow of  $2\frac{1}{2}$  feet per second, will convey 13,000,000 gallons daily. This may be taken as their maximum average daily capacity.

The varying demands of a daily consumption of 13,000,000 will require them to convey from one and a half to two times that amount during certain hours and days of the year, and at such times the loss of head will be seriously felt.

As the consumption in 1874 will be considerably more than 8,000,000, and as it is rapidly increasing, it is plain

there will soon be no surplus capacity of distributing mains, and that the water of the Shawshine, if brought to Boston, must be brought in independent pipes, and that new engines must be provided for pumping it.

#### SCHEME NO. 1.

The scheme of works now to be described provides for an immediate daily supply of 8,000,000 gallons only ; but is so planned that it can be readily enlarged, from time to time, and eventually deliver the entire yield of the Shawshine. Such parts as cannot be economically duplicated, as the conduit, etc., are to be built of the full capacity at the outset, and the estimate will include the cost of building all three of the storage basins, as they are thought essential for the purification of the water.

The dam of the lower, or No. 1, storage basin will be built on the line of the Middlesex canal, the bed of which is 20 feet above the surface of the river at this point. The water in the river will be raised 20 feet, making the level of the water surface of the basin 99 feet above mean high tide.

The old canal between the Shawshine and the Abajonna is in three levels, there having been two locks, each of about seven feet lift, in this distance. It is intended as far as practicable to make use of it for the new conduit, and the elevation and state of preservation of the lower level is such that a very little work upon it will render it serviceable. The height of the bottom of the conduit at the starting-point will be 82 feet above mean high tide, the height of the bottom of the first level of the canal is 99 feet, and that of the second about 92 feet ; hence, on account of the depth of cutting required, it will be advisable to build a closed or covered conduit for the length of these two levels.

The distance from the end of the closed conduit to the point of crossing the Abajonna is 19,200 feet ; the total

length of conduit and canal will be  $11,500 + 19,200 = 30,700$  feet  $= 5\frac{8}{10}$  miles.

Considerable work must be done upon the Abajonna to put it in a proper state for use, such as enlarging its channel in the upper reaches, strengthening the dams along its course, and increasing the length of their overfalls, etc.

Through the conduit, canal and Abajonna river the waters of the Shawshine will flow into Mystic lake.

The gate-house, engine-buildings and stand-pipe will be located at the lower end of the lake, on the westerly side. From the stand-pipe a 42-inch pipe will bring the water over the West Boston bridge to Boston, and connect with the 40-inch Cochituate main at the corner of Beacon and Charles street; a 30-inch sub-main along Cambridge street, from Charles to Hancock, will connect the new 42-inch main with the old 30-inch main leading to the north end of the city.

Before giving the estimate for the entire scheme a few words about the capacity and class of pumping-engine to be adopted are necessary.

A stand-pipe is proposed in place of a reservoir, for economy in first cost, and because with it the head can be more readily adjusted to suit the head of the Cochituate works. It is considered desirable, for so small a supply as 8,000,000 gallons, not to isolate a portion of the city for its exclusive use, but rather to so regulate the pressures that the water from both works may flow through the same pipes. This arrangement will avoid a good deal of changing of the street-mains and pipes, and will ensure an abundant supply for fire purposes in all parts of the city.

In a report upon the high-service supply (City Doc. No. 103, 1873) it was shown that an engine supplying a city without the intervention of a reservoir, or which "has to vary its speed as the consumption of water varies, is required to be about double the capacity of one doing the same work under a uniform speed; that is to say, to furnish a given sup-

ply, an engine pumping into a stand-pipe should have twice the capacity of one pumping into a reservoir."

To meet the case of a supply of 8,000,000 of gallons, and to provide a reserve engine, the minimum of machinery will consist of three engines, each of 8,000,000 capacity; looking to the early increase of supply, however, and bearing in mind the amount of machinery that eventually will be required for the full supply of  $20\frac{1}{2}$  millions, it appears desirable to adopt a larger size of engines, say of 15,000,000 capacity; two of which will be sufficient at first.

Until recently the better classes of pumping engines in this country have given a working duty of about 500,000 lbs. raised one foot high for each pound of coal burnt in the furnace; lately, however, a more expensive class of engine has been introduced, which will give a working duty of fully 800,000 lbs. ft. per pound of coal.

A comparison of the cost of operating these engines, including interest upon first cost, will determine which it is most economical to adopt. For such a comparison the cost of attendance, oil, waste, etc., may be omitted, as it will be the same in each case.

First, an 8,000,000 engine with a working duty of 500,000 lbs. — ft. per pound of coal; lift, 125 feet, —

Cost of engine and boilers, \$60,000.

|                                         |             |
|-----------------------------------------|-------------|
| Interest on cost at 7 per cent. . . . . | \$4,200 00  |
| Coal, 2,720 tons, @ \$8 . . . . .       | 21,760 00   |
|                                         | <hr/>       |
|                                         | \$25,960 00 |

Second, an 8,000,000 engine with a working duty of 800,000 lbs.-ft. per pound of coal; lift 125 feet, —

Cost of engine and boilers, \$90,000.

|                                         |             |
|-----------------------------------------|-------------|
| Interest on cost at 7 per cent. . . . . | \$6,300 00  |
| Coal, 1,700 tons @ \$8 . . . . .        | 13,600 00   |
|                                         | <hr/>       |
|                                         | \$19,900 00 |



The use of the more expensive engine will result in a saving of \$6,060 per year, when the supply is 8,000,000 gallons per day. As the supply increases, the saving will be proportionately greater.

The following is the approximate estimate for Scheme No. 1:—

|                                                                                            |                |
|--------------------------------------------------------------------------------------------|----------------|
| Storage basins . . . . .                                                                   | \$575,350 00   |
| Gate-house, conduit, canal, improvement of<br>the Abajonna, waste weirs, land, etc. .      | 385,000 00     |
| Gate-house, at lake, 200 feet of conduit, en-<br>gine buildings, foundations, well, etc. . | 195,000 00     |
| Two 15,000,000 compound engines; lift 130<br>feet . . . . .                                | 338,000 00     |
| Stand-pipe and connections . . . .                                                         | 35,000 00      |
| Supply-main to Boston, 42 inches diameter                                                  | 856,900 00     |
|                                                                                            | <hr/>          |
|                                                                                            | \$2,385,250 00 |
| Superintendence and contingencies 10% .                                                    | 238,525 00     |
|                                                                                            | <hr/>          |
|                                                                                            | \$2,623,775 00 |

To compare this estimate with those made for other sources of supply and given in the report of the Water Board (City Doc. No. 29, 1873) it will be necessary to compute the cost of delivering each million of gallons, by adding the cost of pumping to the interest, at 6 per cent. upon the cost of works.

With the exception that the delivery-main would be somewhat small, the works as proposed, by the addition of a third engine, are of capacity to furnish a supply of 15,000,000 gallons daily; it will therefore be proper to determine the cost of delivering each million of gallons, with this capacity as a basis. The small size of the main for this supply may be compensated by increasing the lift of the engine, which, by giving a greater head, will increase the velocity of flow.

|                                                    |                |
|----------------------------------------------------|----------------|
| Cost of works on 8,000,000                         |                |
| basis . . . . .                                    | \$2,623,775 00 |
| Add for third engine with                          |                |
| foundations, stand-pipe                            |                |
| connections, etc. . . . .                          | 195,000 00     |
| <hr/>                                              |                |
| Cost of works to deliver                           |                |
| 15,000,000 daily . . . . .                         | \$2,818,775 00 |
| <br>                                               |                |
| Interest upon cost at 6 per cent . . . . .         | \$169,126 50   |
| Yearly cost of pumping 15,000,000 gallons          |                |
| daily ; lift 130 feet . . . . .                    | 43,000 00      |
| <hr/>                                              |                |
| Cost of delivering 5,475,000,000 gallons . . . . . | \$212,126 50   |
| Cost of delivering 1,000,000 gallons . . . . .     | \$38 75        |

It will be seen that the cost of delivering each million of gallons is high, much higher than for the Charles or Sudbury river schemes, — although a cheap class of works very unsatisfactory, and in some respects objectionable or temporary in their character, has been estimated upon. The use of an open canal is in itself decidedly objectionable, on account of evaporation, leakage, cost of maintenance and trouble from ice in winter, where the depth of flow is shallow. In a report made in 1843 by Mr. Caleb Eddy, then agent of the Middlesex Canal Corporation, it is estimated that the loss due to leakage and evaporation is 540,000 gallons per day, per mile of canal ; therefore for 3.6 miles it would be nearly 2,000,000 gallons.

The estimate does not provide for lining the slopes with puddle and masonry ; hence they will be liable to wash, and will require a considerable yearly expenditure for maintenance. The extra cost of making the canal comparatively water-tight, and protecting the slopes, would be about \$235,000. A closed conduit the entire distance between the Shawshine and Abajonna would increase the cost about \$445,000.

A canal, on account of its soft bottom, is difficult and expensive to clean, and is apt to be left until it becomes actually offensive. It is not subject to the self-cleansing processes of a river from periodical freshets.

There is a loss of about 70 feet of head, caused by letting the water down to the level of the Mystic lake, which materially increases the cost of pumping, and in passing the waters through the Abajonna they are mingled with others which have not had the benefit of storage.

A stand-pipe system is in itself an imperfect system, and should not be adopted where a reservoir can be constructed at the required height, and at a reasonable cost.

The bringing of the main supply pipes across a wide and navigable river, on a support of pile work, is a more objectionable feature than might at first glance appear. The pipe is there exposed to accidents that would require days to repair, and the interruption to the supply for any great length of time would stop all manufacturing, and temporarily cause much inconvenience and suffering in the city. Of course, with the Cochituate in reserve, this objection has not great weight so long as the total consumption is not greater than the pipes leading from Chestnut hill and Brookline reservoirs can convey.

The stand-pipe can be connected with Chestnut-hill reservoir, and as the flow in such case would be uniform for the day, the connecting pipe need be only 36 inches diameter. The cost of this pipe would be about \$300,000 less than that of the 42-inch main to Boston via Cambridge.

In the foregoing estimate, and in all those given hereinafter, no allowance is made for mill damages below the point of taking, for interest during construction, nor for cost of negotiating loans.

There are mills of considerable value on the Shawshine at Ballardvale, and as they would be deprived of nearly all

their power, the damages would be high compared with the amount of water and the elevation at which it is taken.

#### SCHEME NO. 2.

In this scheme storage basins upon the river are to be built, as in scheme No. 1. The conduit following the line of the Middlesex canal to Woburn Centre is to be continued to the location of the pumping engines, north of High street, near the corner of Cambridge street, in the town of Winchester.

It is to be covered its entire length; at Woburn Centre, near the corner of Chestnut and Middlesex streets, it turns towards the head of Horn pond, entering the valley of its principal tributary through a tunnel 350 feet long, and crossing the valley in a siphon 900 feet long.

The total length is 56,300 feet, or  $10\frac{2}{3}$  miles. The water is to be elevated into a high level reservoir, built with two compartments, and of a capacity equal to about 120,000,000 gallons; the level of high-water mark in the reservoir is taken at 155 feet above mean high tide; this will deliver the water into the city under about 35 feet greater head than the Cochituate works now give.

Of course the distributing systems of the two works must be independent; but with an elevated reservoir and sufficient capacity of mains leading from it, the separation can be safely made, as an abundant supply for fire purposes can be drawn from either the new or the Chestnut-hill reservoir.

The reservoir is to be connected with the city proper by two 48-inch mains.

The estimate is for the cost of works built of full capacity, that is, capable of delivering in the city an average supply of 20 or 25 million gallons daily, under all the variable conditions that usually attend the consumption. The mains are larger than would ordinarily be provided, the object aimed at being to give them a capacity which will ensure a good pressure in the street-pipes for fire purposes.



## APPROXIMATE ESTIMATE.

|                                                                                                   |                |
|---------------------------------------------------------------------------------------------------|----------------|
| Storage basins . . . . .                                                                          | \$575,350 00   |
| Gate-house and conduit, including land . . . . .                                                  | 1,520,000 00   |
| Engine buildings, foundations, receiving well<br>of large capacity, etc. . . . .                  | 300,000 00     |
| Three compound engines, capacity 15,000,-<br>000 gallons each, lift 86 feet @ \$120,000 . . . . . | 360,000 00     |
| Two 36-inch force mains, 800 feet long each . . . . .                                             | 33,350 00      |
| Reservoir in two compartments, elevation<br>155 feet . . . . .                                    | 525,000 00     |
| Two 48-inch delivery mains, $8\frac{1}{2}$ miles long<br>each . . . . .                           | 2,115,000 00   |
| Cost of connecting with distributing system<br>in city . . . . .                                  | 50,000 00      |
|                                                                                                   | <hr/>          |
|                                                                                                   | \$5,478,700 00 |
| Superintendence and contingencies, 10 per<br>cent. . . . .                                        | 547,870 00     |
|                                                                                                   | <hr/>          |
| Total . . . . .                                                                                   | \$6,026,570 00 |

The supply being  $20\frac{1}{2}$  million gallons daily, the cost of delivering each million would be as follows:—

|                                                     |              |
|-----------------------------------------------------|--------------|
| Interest upon cost of works, at 6 per cent. . . . . | \$361,594 20 |
| Yearly cost of pumping . . . . .                    | 42,000 00    |
|                                                     | <hr/>        |
| Cost of delivering 7,482,500,000 gallons . . . . .  | \$403,594 20 |
| Cost of delivering 1,000,000 gallons . . . . .      | \$53 94      |

The estimate of the cost of works with one force main, one compartment of the reservoir, one engine and one delivery main omitted, that is, proportioned to meet the wants of the immediate future, is \$4,480,000.

In closing this section of the report, it should be stated that the town of Lexington has obtained an act for taking water from Vine brook, which is one of the tributaries of the

Shawshine, and upon which is the location of storage basin No. 2.

The capacities of the storage basins are as follows : —

|                                |                |   |   |               |       |
|--------------------------------|----------------|---|---|---------------|-------|
| Lower                          | basin or No. 1 | . | . | 1,817,957,000 | gals. |
| Bedford                        | “ “ No. 2      | . | . | 490,000,000   | “     |
| Vine brook                     | “ “ No. 3      | . | . | 850,000,000   | “     |
| Total available capacity . . . |                |   |   | 3,157,957,000 | “     |

## CONCORD RIVER.

### QUANTITY.

The Middlesex canal enters the Concord river at the dam in North Billerica. The drainage area of the river above this point as computed from the State map is 350 square miles.

Could reservoirs or basins be built upon it, having a capacity of 20,000 million gallons, it would yield a daily supply of about 200 million gallons ; it would, however, be practically impossible to secure anything like this amount of storage room.

The Concord is formed by the junction of the Sudbury and Assabet in the town of Concord. On the Concord itself no storage room can be had beyond that offered by the mill pond. It has been shown in a previous report, that on the Sudbury seven basins may be built, which, with Farm and Whitehall ponds, will give a capacity of 4,847 million gallons.

The Assabet has not been surveyed, nor examined specially with reference to reservoirs, but it is probable that it offers nearly equal opportunities for their construction with the Sudbury.

The storage capacity of the two streams would hardly reach 10,000 million gallons, or one half the amount required to equalize the flow of the Concord in a dry year. With

this storage the least available yield of the river for a year may be roughly taken to average 150,000,000 gallons daily.

In the towns of Concord and Sudbury are extensive meadow lands, which, while they aid evaporation, act as a sponge to hold back to some extent the summer rains and freshets, and thereby equalize the daily summer flow of the river at and below Billerica.

The following table, although not covering any year of remarkable drought, will serve to give an idea of the summer flow, and its great irregularity, of streams in this climate, where the average rainfall is between 40 and 50 inches : —

*Table showing average daily flow per square mile of water-shed of streams for periods of 7, 5, 4 and 3 months.*

| YEAR. | FROM MAY 31 TO<br>OCT. 31.                                              | FROM APRIL 30<br>TO SEPT. 30.                                           | FROM MAY 31 TO<br>SEPT. 30.                                             | FROM JUNE 30 TO<br>SEPT. 30.                                            |
|-------|-------------------------------------------------------------------------|-------------------------------------------------------------------------|-------------------------------------------------------------------------|-------------------------------------------------------------------------|
|       | 7 MONTHS.                                                               | 5 MONTHS.                                                               | 4 MONTHS.                                                               | 3 MONTHS.                                                               |
|       | Average daily<br>flow, in gallons,<br>per square mile of<br>water-shed. | Average daily<br>flow, in gallons,<br>per square mile of<br>water-shed. | Average daily<br>flow, in gallons,<br>per square mile of<br>water-shed. | Average daily<br>flow, in gallons,<br>per square mile of<br>water-shed. |

## COCHITUATE DISTRICT.

|             |           |           |         |           |
|-------------|-----------|-----------|---------|-----------|
| 1863 . . .  | 1,080,817 | 859,791   | 873,160 | 1,031,319 |
| 1864 . . .  | 630,950   | 419,105   | 294,848 | 298,440   |
| 1865 . . .  | 797,417   | 729,175   | 245,095 | 260,663   |
| 1866 . . .  | 660,173   | 632,633   | 609,638 | 600,658   |
| 1867 . . .  | 790,921   | 664,435   | 519,902 | 566,659   |
| 1868 . . .  | 1,272,457 | 1,276,624 | 722,165 | 657,324   |
| 1869 . . .  | 856,696   | 646,263   | 497,111 | 457,105   |
| 1870 . . .  | 944,395   | 414,562   | 233,453 | 192,664   |
| 1871 . . .  | 509,145   | 453,179   | 358,945 | 373,995   |
| Average . . | 838,107   | 677,307   | 489,368 | 493,203   |

## CROTON RIVER.

|             |           |           |           |           |
|-------------|-----------|-----------|-----------|-----------|
| 1864 . . .  | 531,070   | 450,907   | 269,209   | 237,997   |
| 1865 . . .  | 774,680   | 823,445   | 561,208   | 441,994   |
| 1866 . . .  | 876,184   | 837,075   | 717,891   | 534,548   |
| 1867 . . .  | 1,538,804 | 1,696,865 | 1,697,870 | 1,463,869 |
| 1868 . . .  | 1,869,302 | 1,908,122 | 1,573,948 | 1,507,312 |
| 1869 . . .  | 851,824   | 550,856   | 323,336   | 209,664   |
| Average . . | 1,073,644 | 1,044,545 | 857,243   | 732,564   |



The average daily flow per square mile of water-shed of the Cochituate district was 130,000 gallons in Aug., Sept. and Oct. of 1837; it was 103,100 gallons for 50 days, Sept. 1st to Oct. 21st, 1839; it was 62,900 gallons for the last 5 days of Sept., 1837, and 65,300 gallons for 13 days in 1844. The least average daily flow for a month during nine years in this district was 46,340 gallons per square mile of water-shed. This flow was found for the Charles river to be 192,900 gallons for 50 days, Aug. 21st to Oct., 1845.

If the least daily flow of the Concord be taken at 130,000 gallons per square mile of drainage area, then without storage it will yield a daily supply of 45,500,000 gallons. In a very dry year, and for short periods of a few days, the yield might be less than this, though it is thought that the effect of the meadows above the point of taking would be to equalize the flow at such times. In a report made by State Commissioners appointed in 1861 to make experiments on the Concord and Sudbury rivers, the flow at the Billerica dam on Sept. 8th is given at 50 cubic feet per second, equal to  $32\frac{3}{10}$  million gallons per day; the water above the dam, however, was slowly rising, and the full flow of the river must have been somewhat greater than the discharge over the dam. In the same report it is incidentally mentioned that a discharge at the dam of 100 cubic feet per second is "probably not greater than the ordinary summer flow of the river." This would give a daily flow of  $64\frac{6}{10}$  million gallons.

#### QUALITY.

Chemical analyses of the Concord river water have been made from time to time, and they prove it to be pure and soft; nevertheless, it appears to be the quite general opinion of those most familiar with it, that it is not well suited for a domestic supply.

The junction of the Assabet and Sudbury is about 11

miles above the Billerica dam ; the Assabet rises quite rapidly from this point, but the Sudbury flows through a very level country of meadow lands for the ten or fifteen miles immediately above ; the flow of the Concord from the junction to the dam is also through flat meadow lands. From Wayland to Billerica, a distance of some 25 miles along the Sudbury and Concord, the fall is about three feet.

In the report of the State Commissioners above-mentioned, the following description of the rivers and meadows is found : —

“The meadows alleged to be injured by the dam in question lie along the Sudbury and the Concord, in irregular bodies, from Wayland to Billerica. They lie now upon the right bank of the river, now upon the left, now upon both ; varying in width from a few rods to about a mile. The greatest expanse of meadows is in the towns of Wayland and Sudbury, but they lie in considerable bodies in Concord, Carlisle, Bedford and Billerica. In their present condition they are very wet throughout their whole extent, and in places they are overflowed during the greater part, if not the whole, of the season. The river standing through the year nearly full between the banks, there is no possibility of effective drainage, and the meadows can be of but little value for purposes of agriculture. There are in all about 4,000 acres of these wet meadows.

“The Sudbury and the Concord constitute in fact but one river, running through a very level country, and with remarkably sluggish waters, for a distance of more than 25 miles above the dam in Billerica. A single fact strikingly illustrates the nature of this stream. The bed of the river, for a distance of nearly 25 miles above the dam, at no point rises to a level with the top of the dam.”

The effect of the drainage from this immense extent of boggy meadows is to discolor the water and give it a rather unpleasant taste, and as they lie upon the last stretch of the river above the point of taking, and below all locations for

basins, there is no opportunity to get rid of the color and taste by storage.

Mr. Loammi Baldwin, in a report made in 1834, speaking of the Charles river water, says: "The water of Concord river, from Sudbury to the Middlesex canal, at Billerica mills, has the same defect as to its discolored state, together with the additional objection of its possessing some poisonous quality. I remember when the locks, etc., of the Middlesex canal were built, 30 or 40 years ago, the workmen obliged to labor in the water complained that it made their hands and feet sore, and if a little scratch occurred to their flesh, or the skin was torn or bruised away, the water would cause it to fester into a serious wound, and it was often necessary to suspend working in it that the sore might heal. This character of the water was confirmed to me a few days ago by Mr. Wilson, a master-carpenter, who had been employed 20 years in the direction of the canal-works there, whose expression was, 'If a man gets a little piece of skin knocked off his hand while working in it, the water would fester it up so that I don't know but it would eat his hand up in time; but working in the Merrimack river would wash it well again.'"

In a report made in 1843, by Mr. Caleb Eddy, "Agent for the Middlesex Canal Corporation," to the proprietors of the canal, presenting his views as to the best method of disposing of the canal property, and urging its use for supplying Boston with water, the following answer, applicable to the above given remarks, is found: —

"An idle story has been circulated in regard to the water of Concord river's containing some deleterious substance which would cause a wound by contact with it to '*fester*,' or become greatly irritated. The same tradition adds that washing the part so exposed in the waters of the Merrimack would soon restore it. Carpenters and other mechanics who have been constantly employed on the works of the canal,

and who have been a great many times in the water during the past 30 years, have experienced no such trouble, having daily washed in, and otherwise used it. From experience and inquiries made for the past 20 years, I have not been able to find the origin of this fabrication. It is not impossible but that the blood of the persons who originated the story might have been overheated by the too frequent use of '*strong water*,' particularly when it was sold by authority and used with impunity. Science establishes facts incontrovertible by fable; and the analyses of four able and practical chemists are certainly more to be depended on than all the idle tales that ignorance and prejudice can create."

The water was analyzed at that time by Drs. Charles T. Jackson of Boston, John W. Webster of Cambridge, S. L. Dana of Lowell, and A. A. Hayes, Esq., of Roxbury, and was pronounced by them as pure and soft, and applicable to domestic uses. Dr. Webster says: "The slight yellow color of this water arises from vegetable matter; but this, I found, in a great measure, disappeared after a few days' repose."

The following is an analysis made, by Messrs. Merrick and Gray, of a sample taken from the river at North Billerica, Feb. 20th, 1874: —

"Sample from Concord River.

"This sample was very nearly colorless, with a very faint, or no odor, and some flocculent deposit.

"The unconcentrated water gave an exceeding faint reaction with the Nessler test.

"Analysis gave, —

|                          |                           |
|--------------------------|---------------------------|
| Suspended matter . . .   | 0.16 grs. to 1 U. S. gal. |
| Organic and volatile . . | 1.01 " "                  |
| Inorganic . . . .        | 1.42 " "                  |
|                          | <hr/>                     |
|                          | 2.59                      |



"The inorganic matter contained, —

|                                 |        |                      |   |
|---------------------------------|--------|----------------------|---|
| Silica, sesquioxide or iron,    |        |                      |   |
| alumina, etc. . . . .           | 0.326  | grs. to 1 U. S. gal. |   |
| Chlorine, as chloride of sodium | 0.204  | "                    | " |
| Sulphate of lime . . . .        | 0.660  | "                    | " |
| Albuminoid ammonia . . .        | 0.100  | "                    | " |
| Ammonia . . . . .               | 0.0017 | "                    | " |

This analysis would indicate that the water is unusually free from impurities. It was taken, however, at a season of the year when the vegetable impurities, and consequently the color, are at a minimum.

I am of opinion that for the greater portion of the year it would prove unacceptable for domestic use, unless previously stored for some time.

#### SCHEMES OF WORKS, AND ESTIMATES OF COST.

##### SCHEME NO. 1.

In this scheme it is proposed to take the water from the river at North Billerica, and bring it by a conduit, of the same size and construction as that proposed for Sudbury river, following the line of the old Middlesex canal to Woburn Centre, and from there, the line described for the Shawshine conduit, to the location of the pumping engine, near the corner of High and Cambridge streets in Winchester. Here it is to be pumped into a high level reservoir, of a capacity of 120,000,000 gallons, and brought to Boston in three 48-inch pipes, the works being proportioned for a daily supply of 50,000,000 gallons.

The reservoir is the same as proposed for Shawshine scheme No. 2, and the pipes follow the same line to Boston as the Shawshine pipes.

The elevation of the dam at Billerica is 105 feet above

mean high tide. The total length of the conduit is 74,485 feet, or  $14\frac{1}{10}$  miles. The length of each delivery main is 44,600 feet, or  $8\frac{45}{100}$  miles.

The estimate is for a covered conduit; no estimate is made for an open canal, as, if it is properly protected from leakage, and by masonry lining, it would not cost much, if any, less than the conduit, and then would prove a very unsatisfactory affair, permitting of the contamination of the water, great loss from evaporation, and trouble from ice in winter.

The old Middlesex canal was simply a wide ditch, sometimes in excavation, sometimes in embankment, without lining of any kind, built in perfectly level stretches, and dropped suddenly down from one level to another by locks. It was not designed, and was entirely unsuited, to convey water running with an appreciable current. For the greater part of its length it is in a very fair state of preservation; but in some places it is entirely obliterated; and in others it is grown full of brush, etc. It is entirely above the water level of most of the country through which it passes, and unless thoroughly puddled the loss from leakage would be enormous.

The approximate estimate of cost of works of a capacity to deliver 50,000,000 gallons daily is:—

|                                                                             |                       |
|-----------------------------------------------------------------------------|-----------------------|
| Gate chamber, conduit, waste weirs, land,<br>etc. . . . .                   | \$2,350,000 00        |
| Four compound engines, capacity 17,000,000<br>gals., lift 75 feet . . . . . | 480,000 00            |
| Engine buildings, foundations, receiving<br>well, etc. . . . .              | 350,000 00            |
| Force mains . . . . .                                                       | 60,000 00             |
| Reservoir, in two compartments, elevation<br>155 feet . . . . .             | 525,000 00            |
| <i>Amount carried forward, . . . . .</i>                                    | <i>\$3,765,000 00</i> |

|                                          |                |
|------------------------------------------|----------------|
| <i>Amount brought forward,</i>           | \$3,765,000 00 |
| Three 48-inch delivery mains, including  |                |
| Charles river bridge                     | 3,163,000 00   |
| Cost of connecting mains with city pipes | 75,000 00      |
|                                          | <hr/>          |
|                                          | \$7,003,000 00 |
| Superintendence and contingencies        | 700,300 00     |
|                                          | <hr/>          |
|                                          | \$7,703,300 00 |

The estimate of cost of delivering each million of gallons is :—

|                                             |              |
|---------------------------------------------|--------------|
| Interest upon cost of works, at 6 per cent. | \$462,198 00 |
| Yearly cost of pumping                      | 85,300 00    |
|                                             | <hr/>        |
| Cost of delivering 18,250,000,000           | \$547,498 00 |

Cost of delivering 1,000,000 gallons . . . \$30 00

The cost of works with two engines, one compartment to the reservoir, one delivery main, etc., proportioned for the immediate wants of the city, is . . . \$4,795,000 00

The mill damages would be very large, as the whole flow of the river must be paid for. The entire power at and below the Billerica dam, on the Concord, would be destroyed.

The objections to the scheme are excessive mill damages, the delivery of the water in pretty much the same state that it flows in the river, and the crossing of a long stretch of navigable waters with the main supply pipes.

The estimated cost of works, with a stand-pipe in place of the reservoir, and three 42-inch mains, leading to Chestnut-hill reservoir, is . . . \$6,880,000 00

## SCHEME NO. 2.

To in part remedy the evil of want of storage on the Concord, the water might be turned into the lower basin of the Shawshine, and mixed with the purer water of that river. This scheme will admit of a large saving in the first outlay, as the Concord need not be taken till the consumption reaches the full capacity of the Shawshine.

This perhaps might very properly be considered a Shawshine scheme, but as the Concord determines the capacity of the conduit, engines, mains, etc., I have preferred to class it under the head of Concord river schemes.

The works are similar to those already described, except that the conduit between the Shawshine and Concord is smaller, and the lift of the engines is a little greater.

The approximate estimate of cost is :—

|                                                                           |                |
|---------------------------------------------------------------------------|----------------|
| Storage basins on the Shawshine . . .                                     | \$575,300 00   |
| Gate chambers, conduit, waste weirs, bridge,<br>etc. . . . .              | 2,295,000 00   |
| Engine buildings, foundations, receiving<br>well, etc. . . . .            | 350,000 00     |
| Four compound engines ; capacity 17,000,000,<br>lift 86 feet . . . . .    | 540,000 00     |
| Force mains . . . . .                                                     | 60,000 00      |
| Reservoir, in two compartments, elevation<br>155 feet . . . . .           | 525,000 00     |
| Three 48-inch delivery mains, including<br>Charles river bridge . . . . . | 3,163,000 00   |
| Cost of connecting mains with city pipes .                                | 75,000 00      |
|                                                                           | <hr/>          |
|                                                                           | \$7,583,300 00 |
| Superintendence and contingencies, 10 per<br>cent. . . . .                | 758,330 00     |
|                                                                           | <hr/>          |
|                                                                           | \$8,341,630 00 |



The cost of works with two engines, one compartment to the reservoir, one delivery main, and the conduit brought from the Shawshine only, would be \$4,850,000.00.

With the exception of the impurity of water, this scheme has all the objections of No. 1, and in addition a still larger sum is required to cover mill damages, as the power upon both the Shawshine and Concord must be paid for.

### MERRIMACK RIVER.

The Merrimack has already been reported upon (see City Doc. No. 29, 1873, page 63), in the following terms: "The drainage area above Lowell of the Merrimack river, is between 3,500 and 4,000 square miles, and its minimum summer flow cannot fall short of 1,000,000,000 of gallons in 24 hours.

"It would, therefore, furnish a supply to a population vastly greater in numbers than we have estimated upon.

"The water has at various times been subjected to analysis, and has always been found remarkably free from chemically combined impurities.

"An analysis made by Professor Appleton, for the City of Lowell, in 1869, of a sample taken from above the Pawtucket dam, gave in one U. S. gallon, —

|                              |   |   |   |              |
|------------------------------|---|---|---|--------------|
| Organic and volatile matters | . | . | . | 1.01 grains. |
| Mineral matters              | . | . | . | 1.07 "       |
| Total                        | . | . | . | 2.08 "       |

After filtration, the result was:—

|                              |   |   |   |              |
|------------------------------|---|---|---|--------------|
| Organic and volatile matters | . | . | . | 0.72 grains. |
| Mineral matters              | . | . | . | 0.95 "       |
| Total                        | . | . | . | 1.67 "       |

"It was found to have but half a degree of hardness, and the organic matter to be sanitarily of a harmless nature.

"Although there are several large towns and cities, and many manufactories, on the river above Lowell, the volume of water flowing down is so great that it is not liable to appreciable pollution of a chemical nature, but in certain seasons, especially in the spring, when swollen by melted snow and heavy rains, it is very turbid, and the suspended matter does not readily subside, even when the water is at rest.

"The amount of matter held in suspension at such times is sufficient to render the water somewhat objectionable for domestic use, and entirely unfit for many manufacturing processes.

"The following extract from the report of Mr. Burbank, made to the City of Lowell in 1869, will show the nature of the sediment and the difficulty of its removal: —

"The experiments here described were made for the purpose of determining the amount and character of the sediment contained in the water of the Merrimack, at a time when it contained nearly the maximum quantity of impurities in suspension.

"The water for these experiments was taken from the river above the dam, April 29th, 1869, and glass tubes were filled with it to the depth of six feet.

"A whitish sediment began to fall immediately and in half an hour covered the bottom of the tubes.

"During the first twelve hours this sediment accumulated rapidly, and the water became perceptibly clearer in the upper part of the tubes. A considerable amount of matter remained suspended, however, and in forty-eight hours from the time the tubes were filled, the water was still quite turbid throughout.

"After standing ten days the heavier matter had subsided, but the water still retained a whitish, opalescent appearance, from the clay in suspension. It was then allowed to stand

for twenty days longer, when the sediment appeared to be all deposited.

"The sediment from three gallons measured (wet)  $\frac{32}{100}$  of a cubic inch. About one-fourth of the bulk of this material was light, flocculent matter, which at first occupied a much larger space. (The sediment from the three gallons weighed, when dry, 46.68 grains).'

"It appears, then, that in certain conditions of the water, at least thirty days of perfect quiet are required to allow the suspended matter to entirely deposit itself; it also appears that the amount of sediment from a daily supply of 50,000,000 of gallons would be so large as to entail a considerable expense for its removal.

"If it be supposed that the turbid condition continues for sixty days in the year, and that the average quantity of matter in suspension during that time is one-half only of that given by the above experiment, it will be found that the yearly deposit from a daily supply of 50,000,000 of gallons will amount to 3,430 cubic yards, and will weigh 1,490 tons.

"The cost of settling-basins of sufficient capacity to allow the water to remain undisturbed for thirty, or even ten days is too great to admit of their use. Filtration would be the only practicable method of freeing the water from its mechanical impurities.

"Filters cost much more to operate than do settling-basins, but they very materially shorten the time required for the clearing process.

"The water should be taken from the river above the Pawtucket dam in Lowell, before it has been deteriorated by the discharge from the factories. On account of the level of the land between this point and Boston, the conduit will have to be so located as to require two pumping-stations; one at the Merrimack, to elevate the water to the conduit, the other at or near Charles river, to elevate the water to Chestnut-hill reservoir.

"The scheme of works upon which the estimate is based, is, then : a pumping-station, settling basins and filters at or near Lowell ; a conduit 25 miles long, leading to Charles river in Watertown ; a pumping-station at the Charles, and force-mains about two miles long leading to the reservoir.

"The supply being 50,000,000 gallons per day, the estimated cost of the works, of a capacity to furnish it, is \$13,-065,000.00. The estimated cost of delivering each million gallons is :—

|                                              |   |              |
|----------------------------------------------|---|--------------|
| Interest at 6 per cent. upon \$13,065,000    | . | \$783,900 00 |
| Yearly cost of pumping and operating filters | . | 195,000 00   |
| <hr/>                                        |   |              |
| Cost of delivering 18,250,000,000 gallons    | . | \$978,900 00 |
| Cost of delivering 1,000,000 gallons         | . | 53 64        |

"The estimated cost of works, with a portion of the filters, settling-basins and pumping machinery omitted (that is proportioned to meet the wants of the immediate future), is \$10,440,000.00.

"It should be stated that filtration, on an extensive scale, has not yet been tried in this country, and although successfully practised in England and on the continent, it is not unattended with difficulties and failures at times. In a climate like ours, with its severe winters and warm summers, the difficulties would be materially increased."

The line of conduit in this scheme followed the Middlesex canal as far as Woburn Centre, and then followed a very direct line to Watertown.

At the time the above-quoted report was made very little study had been given to this or any of the sources then considered, as the necessity for a temporary addition to the Cochituate supply was pressing, and the legislative action involved required a decision as to the source of supply before



sufficient time for an exhaustive comparison of the various available sources could be made. No surveys whatever had been made, and the distances for estimates were taken from maps, and the quantities of work, such as excavation, masonry, etc., were computed from a hurried reconnoissance of the grounds and from comparison with executed works in other parts of the country.

It will be seen, however, by a comparison of the estimate for the Sudbury river, given in the Appendix to the report upon "Additional Supply," with that given in the body of the report, which was made after preliminary surveys and plans and a careful study of the grounds had been made, that the very rough comparative estimates of the Appendix are not greatly in error. The plans of works there proposed for the various sources, however, are not in all instances the best, though usually the cheapest.

This much is said, because some of the criticisms of this report that have appeared do not take into consideration the circumstances under which it was made; but, on the contrary, assume that the schemes and estimates given in the Appendix were put forth as definitive.

The scheme for the Merrimack now estimated upon is in most of its details identical with that already given; but instead of locating the second pumping-station at Watertown, it is to be located in Winchester at the point selected for the Shawshine and Concord schemes, and the reservoir and distribution mains are to be the same as for the latter schemes.

The surveys have not been extended beyond the Concord; the distance from the Concord to the Merrimack, — about six miles — is taken from the map, and the cost of the conduit for this distance is determined from that of the Sudbury river conduit.

The approximate estimate of cost for works of a capacity to deliver a daily supply of 50,000,000 gallons is: —

|                                                                                                                                     |                 |
|-------------------------------------------------------------------------------------------------------------------------------------|-----------------|
| Gate-chamber, river work, settling-basins,<br>filters, etc. . . . .                                                                 | \$3,256,000 00  |
| Four compound pumping-engines at or near<br>Lowell; capacity, 17,000,000 gallons daily;<br>lift 50 feet . . . . .                   | 400,000 00      |
| Engine-buildings, foundations, etc. . . .                                                                                           | 260,000 00      |
| Conduit, including Concord river bridge,<br>waste weirs, land, etc. . . . .                                                         | 3,419,000 00    |
| Four compound engines at Winchester; ca-<br>pacity, 17,000,000 gallons; lift 75 feet, with<br>buildings and foundations, etc. . . . | 864,000 00      |
| Force mains . . . . .                                                                                                               | 60,000 00       |
| Reservoir in two compartments; elevation,<br>155 feet . . . . .                                                                     | 525,000 00      |
| Three 48-inch delivery mains, including<br>Charles river bridge . . . . .                                                           | 3,163,000 00    |
| Cost of connecting mains with city pipes .                                                                                          | 75,000 00       |
|                                                                                                                                     | <hr/>           |
|                                                                                                                                     | 12,022,000 00   |
| Superintendence and contingencies, 10 per<br>cent. . . . .                                                                          | 1,202,200 00    |
|                                                                                                                                     | <hr/>           |
|                                                                                                                                     | \$13,224,200 00 |

The cost of delivering each million of gallons is as follows: —

|                                               |              |
|-----------------------------------------------|--------------|
| Interest upon cost of works at, 6 per cent. . | \$793,452 00 |
| Yearly cost of pumping and operating filters  | 160,000 00   |
|                                               | <hr/>        |
| Cost of delivering 18,250,000,000 gallons .   | \$953,452 00 |
| Cost of delivering 1,000,000 gallons . . .    | \$52 24      |

The cost of works proportioned for immediate use is \$7,800,000.00.

There appear to be no objections to this scheme, except

complexity and great cost. In other respects I regard the Merrimack as the best source from which the city can take a large supply.

The mill damages would be excessive, unless the State Legislature can grant the right to take a certain definite daily supply upon which the award for damages would be made, and fears of danger might be entertained by some persons from the large amount of sewage that is turned into the river at Concord, Manchester, Nashua and other places in New Hampshire and Massachusetts.

CONDUIT FROM FARM POND TO LAKE COCHITUATE, AND FROM  
LAKE COCHITUATE TO CHESTNUT-HILL RESERVOIR.

Farm pond can be easily connected with the lake by a covered conduit, but to connect the lake with Chestnut-Hill reservoir by an aqueduct of large capacity, many obstacles must be overcome, and work of a very expensive character is required.

In a report made Jan. 27, 1873 (see City Doc. No. 29, page 40), in speaking of the Sudbury river conduit, it was said: "It would on many accounts be desirable to so locate the new conduit that water may be drawn through it from the lake; but there is a serious difficulty in the way, due to the low rate of fall that can be obtained between the lake and Chestnut-hill reservoir.

"To preserve the present storage capacity of the lake, a fall of less than two inches per mile can be allowed, after deducting the necessary fall for the siphon at Charles river. So small a rate of fall would necessitate a conduit of fully twelve feet in diameter, to equal in flowing capacity one of eight and a half feet with a grade of twelve and two thirds inches per mile.

"By reducing considerably the storage capacity of the

lake, a fall of three inches per mile can be secured ; but even this would require a conduit of eleven and one-seventh feet diameter to equal one of eight and a half feet located as above described.

"The extra cost of either of the two large conduits above the small one would be a large sum, and, beyond this, their location must of necessity be unfavorable.

"The elevation of low water in Farm pond is  $146\frac{3}{4}$  feet ; that of low water in Lake Cochituate, taken at four feet above the bottom of the conduit, is 125 feet above tide marsh level, or only about one foot greater than high-water level in Chestnut-Hill reservoir."

The Sudbury water, it is believed, is as free from impurities — especially impurities of a noxious character — as that of any source of large capacity within the reach of Boston, excepting only the Merrimack river and the Middleborough ponds.

In certain seasons, however, it takes up considerable vegetable matter, which imparts to it a deep color, and affects its taste in a slight degree. In this respect it does not differ from the Charles, Neponset and other streams and small rivers of this vicinity. The Merrimack, with its large volume of flow, coming down from the granite regions of New Hampshire, and passing over a rocky and sandy bed, is not so liable to become discolored, yet at times it takes on a very perceptible tinge.

The impurities which produce this color are in quantities that do not affect the salubrity of the water, but the color itself is quite objectionable, and should be in some way destroyed.

Chemistry would suggest, and it has been found by experience, that discolored water becomes clear again after an exposure to the air of a few days or weeks, in basins or other places where new matter cannot be taken up.

Mr. Bateman, a celebrated hydraulic engineer of England,



in his evidence before the Royal Commission of 1867, on Water Supply, says: "Any color with which the streams may occasionally be charged is discharged on exposure in these large reservoirs, or by subsidence. Loch Katrine, which is probably as fine a body of pure water as any in the world, and is almost absolutely colorless, is fed by mountain streams, which in summer and in autumn are as brown as porter. I have never seen a darker stream, even from a bog in Ireland, than the river Strowan, which flows into Loch Katrine, and is one of the principal contributors to it on the northern side of the lake; but all the color is discharged by exposure to the atmosphere in so large a surface, namely, 3,000 acres. That is also the case in the Manchester water-works, and in all the other water-works where the water is collected in a large body; however colored it is in the first instance, its impurities become removed by time and exposure." So also the waters of brooks that feed Lake Cochituate mostly flow through meadow lands, and are very highly colored in the late summer and fall; yet before they leave the lake they become clear and almost colorless.

The proposed storage basins will do much towards removing the vegetable impurities; nevertheless, at the very outset in the study of the Sudbury as a source of supply, it was felt that it was desirable to pass its waters through Lake Cochituate, even at a considerable cost, as the slow passage and deep water would tend to still further purify them.

To do this would necessitate a new aqueduct from the lake to Chestnut-hill reservoir, and to ascertain if such an aqueduct were practicable, the ground about the lake was quite carefully examined, though no surveys were made; but no satisfactory route was found. The old conduit occupied the only practicable line, and the building of a new one near to and parallel with it would be not only expensive, but also attended with great risk of interrupting the present supply to the city.

In many places the old conduit is on steep hillsides, or in narrow valleys, where there is no room for a second one; it passes through the villages of Wellesley and Grantville, which have become quite thickly settled since its construction, and through which it would be impossible to get a new line without destroying much property. The cut in Grantville is quite deep. The section most difficult and costly to build, and the construction of which would be attended with the greatest risk, would be the first mile from the lake. Great trouble was found in building the existing conduit through this section, on account of the quicksand and large quantity of water encountered, although at that time the lake was drawn down much below its present level. The difficulties overcome here are well described in a speech made by Mayor Quincy in 1848, at the time of the water celebration: —

“The obstacles to be overcome have not been of a light or trivial nature. The aqueduct, after leaving the gate-house at the lake, follows up the valley of Snake brook to a dividing ridge that separates the waters of the Charles from those of the Merrimack. In this distance the difficulties encountered in the construction of conduit masonry arose from the character of the material in the foundation, no less than from the amount of water to be removed by pumps. The conduit lies wholly in excavation, varying from 15 to 52 feet in depth, and for three-quarters of a mile occupies the bed of Snake brook, at an average level of 23 feet below the ordinary surface of its waters.

“The narrowness of the valley rendered it necessary to maintain an open channel for this brook parallel to the line and not more than 25 feet distant. From the slight descent of the brook, and the extent of the country drained by it, it was impossible to prevent a periodical overflow, which, as the material was quicksand, produced the most disastrous results,

the banks caving in and covering unfinished work, and rendering it as difficult of completion as when it was begun.

"At times like these there was no cessation of labor; night forces relieved day forces, and the five steam engines, attached to pumps capable of raising 12,000,000 of gallons 10 feet high in twenty-four hours, were constantly employed, and at times their extreme capacity failed to free the excavation. Unaided by steam this work could not have been performed in less than five years, and the expense of constructing the conduit in quicksands subject to inundations for that length of time would have increased in still greater proportions.

"In the same section the extreme hardness of the rock, was such as to require seven times the amount of labor and powder usually required for the same amount of rock excavation."

To build a new conduit in this section at a still lower grade (to secure the necessary depth of flow for an aqueduct of large capacity, without lessening the storage capacity of the lake, will require it to start at a lower level than the old aqueduct), without destroying the old one, may be said to be impracticable. And even if it could be readily built, to locate a second conduit alongside the first one would not be desirable, as an accident to the one would endanger the other.

Some other outlet from the lake than the valley of Snake brook must be sought then. A very brief examination of the ground will show that on the easterly side no such outlet can be had except by a long tunnel, which would probably encounter much quicksand, and would be 15 or 16 feet below the high-water level of the lake. The difficulties to be overcome in building such a tunnel cannot be foreseen; all that is positively known is, they would be great, and would much retard the completion of the work.

The topography of the ground to the south of the lake is such that by a rather deep excavation a conduit may be built, following a southerly direction, a distance of about 7,500

feet to the line of the proposed Sudbury river or Farm-pond conduit, and joining it near the entrance to the first tunnel.

As the conduit from Farm pond would enter at the southerly end also, the water would not have the benefit of the passage through the lake, and as the chief tributary of the lake enters at this point, the Cochituate water would itself be delivered in a less agreeable state than now.

At the point where the new Cochituate conduit would join the proposed Farm-pond conduit, the level of the former would be 17 or 18 feet lower than that of the latter. The high cost of the Farm-pond conduit is, in a great measure, due to the deep cutting and tunnel work required; on the grade necessary for the new Cochituate conduit this cost would be very greatly increased.

The slight difference in the low-water level of the lake, and the high-water mark of Chestnut-hill reservoir, would give a very flat grade, only two or three inches to the mile, requiring a very large sectional area to give a flowing capacity equal to that proposed for the Sudbury river conduit, and consequently would increase very materially the amount of the mason work. The difference in cost per running foot of the two conduits is estimated at \$13 for mason work alone.

These reasons were considered conclusive against carrying the new aqueduct through or by way of the lake.

The order of the City Council, in answer to which this section of the report is written, requires that an estimate be made for a conduit from the lake to the reservoir, passing Charles river by a high level bridge.

At Newton Lower Falls, where the old conduit crosses, the Charles-river valley is quite wide, and a high level bridge at that point will be very expensive. At the Upper Falls, where the Farm-pond conduit line crosses, the valley is much narrower, and the cost of the bridge would be much less, but to carry the conduit to this point the valley of Rosemary brook must be



crossed, requiring either another expensive high level bridge, or a syphon 1,700 feet in length; as the two bridges would be much more costly than the one at Newton Lower Falls, the point of crossing for the line to be estimated upon has been taken at the latter place.

This line starts from the eastern shore of the lake, about 1,200 feet north of the Worcester turnpike, and runs in an easterly direction, through the valley of Pickerel and Mud ponds, and, turning somewhat to the north, joins the old conduit line near its intersection with Oak street. From here it follows alongside the old conduit to Newton Centre, where it deflects to the right, following the line proposed for the Sudbury-river conduit, through the Beacon-street tunnel, to Chestnut-hill reservoir. The total length from the lake to the reservoir is 64,500 feet.

The first 1,100 feet from the lake is in rather deep sand cutting, in which the water, when the lake is full, would stand 15 or 16 feet deep. The next 4,000 feet is in tunnel, the first portion of which, at least, would be in wet sand and gravel. As has been before said, it is impossible to give anything like a reliable estimate of the cost of this portion of the work. Also the cost of protecting the old conduit while building a new one beside it is a matter of considerable uncertainty.

The following is the approximate estimate: —

|                                                                                                                            |              |
|----------------------------------------------------------------------------------------------------------------------------|--------------|
| Cost of conduit from Farm pond to the lake,<br>including gate-house at pond, railroad<br>crossings, culverts, etc. . . . . | \$562,000 00 |
|----------------------------------------------------------------------------------------------------------------------------|--------------|

#### CONDUIT FROM LAKE TO RESERVOIR.

|                                                                                                    |                       |
|----------------------------------------------------------------------------------------------------|-----------------------|
| Earth and rock excavation and embankment,<br>including sheeting, pumping, ditching<br>etc. . . . . | 975,000 00            |
| Stone and brick masonry of conduit sec-<br>tion . . . . .                                          | 1,895,700 00          |
| <i>Amount carried forward, . . . .</i>                                                             | <u>\$3,432,700 00</u> |

|                                                                                 |                |
|---------------------------------------------------------------------------------|----------------|
| <i>Amount brought forward,</i>                                                  | \$3,432,700 00 |
| Tunnels                                                                         | 860,000 00     |
| Charles-river bridge                                                            | 527,000 00     |
| Gate-house, waste weirs, culverts, road crossings, protecting old conduit, etc. |                |
| etc.                                                                            | 245,000 00     |
| Land damages                                                                    | 150,000 00     |
| Inlet chambers and works at reservoir                                           | 172,000 00     |
|                                                                                 | <hr/>          |
|                                                                                 | \$5,386,700 00 |
| Superintendence and contingencies, 10 per cent.                                 | 538,670 00     |
|                                                                                 | <hr/>          |
|                                                                                 | \$5,925,370 00 |

To show the cost of the whole scheme for bringing water from Sudbury river by this route, there must be added to the above the cost of:—

|                                                           |                |
|-----------------------------------------------------------|----------------|
| Three storage basins, dams, etc.                          | \$495,000 00   |
| Wooden pipes connecting dams                              | 70,200 00      |
| Work at Farm pond                                         | 8,500 00       |
| Pipe to connect the conduit with reservoir outlet chamber | 72,318 00      |
| Land damages, including mill property flowed              | 255,000 00     |
|                                                           | <hr/>          |
|                                                           | \$901,018 00   |
| Add cost of conduit, as above                             | 5,925,370 00   |
|                                                           | <hr/>          |
|                                                           | \$6,826,388 00 |

#### ANALYSES OF CHARLES RIVER WATER.

A great number of analyses of Charles-river water have been made since the question of bringing a supply of water to Boston was first agitated.

During the early days of the discussion, from 1834 to 1845, the purity of this water was a matter of animated, almost bitter controversy, and quite a number of opinions on the subject were then published.

To quote them in full would occupy too much space; it will be well, however, to bring together the various analyses, and to give the opinions in brief.

In a report made in 1834 by Loammi Baldwin, the results of an analysis by Dr. C. T. Jackson, of a sample (F) "taken by the falls in Watertown" are given:—

"F. Clear, transparent and colorless; has a few flocculi. No animalculi. Specific gravity, 1.0005. 5,000 grs. evaporated to dryness leave 0.1 grs. vegetable matter."

He speaks of this water, among others, as being "sufficiently pure for the ordinary uses of life."

Mr. Baldwin, after speaking of the poisonous qualities of the Concord-river water, as before quoted (page 25), says: "This natural defect of streams flowing through extensive boggy soil, and lying as the water does in winter and spring, and often in summer, upon immense fields of morass lands bordering on the Charles and Concord, should induce great caution in taking their waters for the supply of towns."

In the report of 1837, by Commissioners Treadwell, Baldwin and Hale, the following results of an analysis by A. A. Hayes, are found:—

"No. 4. [Charles river.] Nearly colorless, has no perceptible odor, is more brisk and sparkling than either of the specimens.

"100,000 lbs. give by repeated trials, 3,741 pound bulks of mixed gases, which were decomposed into oxygen, 2,040, nitrogen, 1,701.

"A trace of carbonic acid only, can be observed; the excess of oxygen is an unusual fact; 3.32 lbs. result from the evaporation of 100,000 lbs. at 212° F.

" This weight is reduced by heating to 1.80 lbs., consisting of

|                                                                |                        |           |
|----------------------------------------------------------------|------------------------|-----------|
| Sulphate of soda . . .                                         | $0.06 \times 2$        | 0.12 lbs. |
| Chloride of sodium . . .                                       | $0.29 \times 2$        | 0.58 "    |
| Carbonate of lime . . .                                        | $0.42 \times 2 = 0.84$ | "         |
| Silicious earth, clay, and trace of<br>iron and magnesia . . . | $0.13 + 2 = 0.26$      | "         |
| " For 50,000 . . .                                             | <hr/> 90               | 1.80 "    |

The Commissioners say, " We have found the water of this river more colored than that of Spot pond, Long pond, or Mystic pond. The chemical analysis, however, shows it to be a very pure water. Notwithstanding this, we consider the presence of coloring matter as a serious, though not an insuperable objection."

In 1845 various pamphlets were published in opposition to the Long pond or Cochituate scheme, and generally favoring the taking of water from Charles river. In one of these pamphlets by John H. Wilkins, Esq., it was contended that the Charles-river water was superior to that of Long pond. These pamphlets were answered by Commissioner Hale, who devoted several pages to the discussion of the purity of the waters. He objected to that of Charles river on account of its color and the amount of sewage it received in 50 miles of its length above Watertown.

Analyses of two samples by B. Silliman, Jr., are given in a report made in 1845 by Commissioners John B. Jervis and Walter R. Johnson. They are as follows:—

No. 6 was taken from the river at Watertown, July 29, at six P. M. No. 7 was taken at South Natick, July 22, at nine A. M.

|                                     | No. 6. | No. 7. |
|-------------------------------------|--------|--------|
| Grains of solid in one gallon . . . | 3.40   | 2.53   |
| Volatile at redness . . . .         | 0.85   | 0.86   |
| Leaving solid matter . . . .        | 2.55   | 1.668  |



## No. 6.

|                                                                                      | Grains.      |
|--------------------------------------------------------------------------------------|--------------|
| Chloride of sodium . . . . .                                                         | .1984        |
| Sulphate of soda . . . . .                                                           | .0830        |
| Sulphate of potassa . . . . .                                                        | .0310        |
| Sulphate of magnesia . . . . .                                                       | .1350        |
| Carbonate of lime . . . . .                                                          | .4970        |
| Carbonate of magnesia . . . . .                                                      | .1300        |
| Sulphate of lime with silica . . . . .                                               | .6810        |
| Carbonate of soda, equivalent to crenate and nitrate<br>of ditto, and loss . . . . . | .7116        |
|                                                                                      | <hr/> 2.5500 |
| Carbonic acid to the gallon, in cubic inches . . . . .                               | 5.058        |

## No. 7.

|                                                                                      | Grains.      |
|--------------------------------------------------------------------------------------|--------------|
| Chloride of sodium . . . . .                                                         | .1547        |
| Sulphate of soda . . . . .                                                           | .3816        |
| Chloride of calcium . . . . .                                                        | .0420        |
| Sulphate of lime and silica . . . . .                                                | .2624        |
| Phosphate of alumina . . . . .                                                       | .0973        |
| Carbonate of lime . . . . .                                                          | .1610        |
| Carbonate of magnesia . . . . .                                                      | .0399        |
| Carbonate of soda, equivalent to crenate and nitrate<br>of ditto, and loss . . . . . | .5291        |
|                                                                                      | <hr/> 1.6680 |
| Carbonic acid in one gallon, in cubic inches . . . . .                               | 0.464        |

Mr. Silliman says that these and a number of other waters he examined "are all remarkably free from foreign matters."

The commissioners, in their remarks upon samples, say : —

"Sample No. 6 was taken on the afternoon of July 26, from Charles river, at Watertown, 150 feet above the lower

dam, where the current appeared to be the most rapid. When first collected its odor was strongly marked by the peculiar smell of marsh water; floating fibres were numerous, and at least two species of animalcules were observed. The taste was somewhat styptic, — savored decidedly of stagnant pools, and was characterized by a kind of astringency like that left on the tongue by tan, or certain slightly acrid barks and roots. This continued to be perceived for half an hour after tasting the water. After several weeks the insects died, the odor was nearly lost, and only the peculiar styptic taste remained. When first collected the taste of this water was highly objectionable."

"Sample No. 7 is from Charles river at South Natick. It was collected in a mill-pond at that place, midway between the banks, and, by estimation, about 200 feet above the dam. This water had a yellowish color, a taste and odor both savoring of the marsh and animalcules in small numbers."

In the report of the State Board of Health for 1873, will be found a very interesting paper on the present condition of certain rivers of Massachusetts, by Prof. Wm. Ripley Nichols. It throws so much light upon the general question of purity of river waters that, with consent, it is reproduced here in Appendix II. In it will be found a great number of analyses of Charles river and other waters, and the views of Prof. Nichols on this and other rivers as sources for domestic supply. There is an Appendix to it, giving the result of a number of chemical examinations made by J. M. Merrick in the early part of last summer, for the town of Brookline.

The order of Feb. 16 requires that the purity of the water of Charles river, at the most expedient point of taking the same for the use of the City of Boston, shall be ascertained.

Without a much more thorough study of the river than it has been possible to make, the location of this point cannot be determined. In the preliminary report of Feb. 13, 1872,

it was stated that the best point "is between Newton Lower and Upper Falls." A more familiar acquaintance with the valley of the Charles places this statement in doubt, and it will be seen by reference to City Doc. No. 29 of 1873, page 74, that even at that date this doubt was felt to a certain extent. It is there said, "The Charles is the natural drain of a territory which in the future will support a large population, and its waters will be liable to appreciable pollution from the sewage of that population, requiring either special means for its purification or a removal of the pumping station to a more distant point."

The river after passing South Natick flows for nearly 20 miles to Newton Upper Falls through a flat country, chiefly of meadow lands, with only one dam in that distance. In this respect it is somewhat similar to the Concord above Billerica, though the extent of meadows is not nearly so great. In this distance no opportunity for a storage basin offers itself, and it is thought that to store water at some point above South Natick, and then pass it down as wanted in the summer season, through such a channel bordered by a considerable population, which is destined to increase largely in the future, would tend to so far contaminate it as to render it at least suspicious.

Even for a long distance above South Natick it is not certain that a basin could be formed of sufficient depth to insure the purity of the water; in fact, an eye examination of the grounds leads to the conclusion that such a basin cannot be built; if, however, surveys should prove the contrary, and a dam a little above South Natick would secure capacious storage room, there seems to be no reason why water taken at this point should not be as good, in all respects, as that taken from storage basins on the Sudbury or any other similar stream.

The summer flow of the Charles at Newton is between 20 and 30 million gallons per day, and for a day or two at a time it may be reduced to 10 or 12 millions. It will be

necessary, therefore, to build storage basins to obtain a large supply from it, and in a dry season the dams of these basins will stop entirely the natural flow of the river. As at such times it will be necessary to husband the water, only so much as is needed for the supply of the city will be allowed to pass the dams, and if then it have a run of many miles, through meadow lands and past a number of villages, it will take up considerable foreign matter, and in this condition will be pumped directly into the distributing reservoirs. If this view be correct, the water should be taken directly from the storage basin, or somewhere above South Natick.

On the other hand, if the water be taken at some point near Newton Upper Falls, the works for conveying it to the distributing reservoirs will cost very much less, and as for the first few years the quantity taken will be so small that even the summer flow of the river can be made to largely exceed it, and as at present the amount of sewage carried into the channel between South Natick and the Upper Falls is not large, it is possible that true economy would require locating the pumping engines at this point, having in view always their ultimate removal to or beyond South Natick.

The objection would still obtain, however, of delivering the water into Chestnut-hill reservoir in its discolored state.

As this uncertainty existed in regard to the most expedient point of taking, I have had four samples analyzed, one from Newton Lower Falls, one from Newton Upper Falls, one from near Spring-street bridge, and the fourth from South Natick. The analyses were made by Messrs. Merrick and Gray, and give the following results:—

SAMPLE FROM NEWTON LOWER FALLS, TAKEN FEB. 19, 1874.

"This was nearly colorless, almost, or quite inodorous with some fine flocculent deposit.

"The unconcentrated water gave a very faint reaction with the Nessler test.



" Analysis gave, —

|                             |       |       |                              |   |   |
|-----------------------------|-------|-------|------------------------------|---|---|
| Suspended matter            | . . . | 0.23  | grs. to 1 Amer. (U. S.) gal. |   |   |
| Organic and volatile matter | 1.22  | "     | "                            | " | " |
| Inorganic matter            | . . . | 1.38  | "                            | " | " |
|                             |       | <hr/> |                              |   |   |
|                             |       | 2.83  |                              |   |   |

" The inorganic matter contained, —

|                                            |       |       |   |   |   |   |
|--------------------------------------------|-------|-------|---|---|---|---|
| Silica, sesquioxide of iron, alumina, etc. | . . . | .444  | " | " | " | " |
| Chlorine as chloride of sodium             | . . . | .277  | " | " | " | " |
| Sulphate of lime                           | . . . | .870  | " | " | " | " |
|                                            |       | <hr/> |   |   |   |   |
| Albuminoid ammonia                         | . . . | .0130 | " | " | " | " |
| Ammonia                                    | . . . | .0025 | " | " | " | " |

SAMPLE FROM NEWTON UPPER FALLS, TAKEN FEB. 19, 1874.

" This was nearly colorless, almost inodorous with some flocculent deposit.

" The unconcentrated water gave a faint reaction with the Nessler test.

" Analysis gave, —

|                             |       |       |                            |   |   |
|-----------------------------|-------|-------|----------------------------|---|---|
| Suspended matter            | . . . | .31   | grs. to 1 American gallon. |   |   |
| Organic and volatile matter | .96   | "     | "                          | " | " |
| Inorganic matter            | . . . | 1.21  | "                          | " | " |
|                             |       | <hr/> |                            |   |   |
|                             |       | 2.48  |                            |   |   |

" The inorganic matter contained, —

|                                            |       |       |                      |   |   |
|--------------------------------------------|-------|-------|----------------------|---|---|
| Silica, sesquioxide of iron, alumina, etc. | . . . | .296  | grs. to 1 Amer. gal. |   |   |
| Chlorine as chloride of sodium             | .108  | "     | "                    | " | " |
| Sulphate of lime                           | . . . | .296  | "                    | " | " |
|                                            |       | <hr/> |                      |   |   |

|                    |   |   |      |                      |
|--------------------|---|---|------|----------------------|
| Albuminoid ammonia | . | . | .012 | grs. to 1 Amer. gal. |
| Ammonia            | . | . | .003 | " " "                |

SAMPLE FROM NEAR SPRING-STREET BRIDGE, TAKEN FEB.  
19, 1874.

"This sample was almost colorless, with a very faint odor, and some flocculent deposit.

"The unconcentrated water gave a prompt reaction with the Nessler test.

"Analysis gave, —

|                             |   |      |       |                         |
|-----------------------------|---|------|-------|-------------------------|
| Suspended matter            | . | .    | .28   | grs. to 1 U. S. gallon. |
| Organic and volatile matter | . | 1.12 | "     | " "                     |
| Inorganic matter            | . | 1.66 | "     | " "                     |
|                             |   |      | <hr/> |                         |
|                             |   |      | 3.06  |                         |

"The inorganic matter contained, —

|                                            |       |       |       |   |   |
|--------------------------------------------|-------|-------|-------|---|---|
| Silica, sesquioxide of iron, alumina, etc. | .     | 0.32  | "     | " | " |
| Chlorine as chloride of sodium,            | 0.241 | "     | "     | " | " |
| Sulphate of lime                           | .     | 0.662 | "     | " | " |
|                                            |       |       | <hr/> |   |   |
| Albuminoid ammonia                         | .     | .015  | "     | " | " |
| Ammonia                                    | .     | .004  | "     | " | " |

SAMPLE FROM SOUTH NATICK, TAKEN FEB. 20, 1874.

"This was very nearly colorless, with a very faint odor and some flocculent deposit.

"The unconcentrated water gave a faint reaction with the Nessler test.

"Analysis gave, —

|                             |   |      |       |                         |
|-----------------------------|---|------|-------|-------------------------|
| Suspended matter            | . | .    | .24   | grs. to 1 U. S. gallon. |
| Organic and volatile matter | . | .91  | "     | " "                     |
| Inorganic matter            | . | 1.54 | "     | " "                     |
|                             |   |      | <hr/> |                         |
|                             |   |      | 2.69  |                         |

The inorganic matter contained, —

|                                                    |       |                         |   |   |
|----------------------------------------------------|-------|-------------------------|---|---|
| Silica, sesquioxide of iron, alumina, etc. . . . . | .338  | grs. to 1 U. S. gallon. |   |   |
| Chlorine as chloride of sodium, .                  | .103  |                         | “ | “ |
| Sulphate of lime . . . .                           | .463  |                         | “ | “ |
| <hr/>                                              |       |                         |   |   |
| Albuminoid ammonia . . . .                         | .012  |                         | “ | “ |
| Ammonia . . . . .                                  | .0025 |                         | “ | “ |

The above results show the Charles-river water to be very pure, and that last February it was quite free from color. The sample taken at South Natick, or from the highest point on the river from which any samples were taken, was the most discolored of all, but its tinge was hardly perceptible.

I am indebted to Mr. A. Fteley, Resident Engineer in charge of Additional Supply, and his assistants, for the surveys and estimates of quantities, and other valuable assistance.

JOS. P. DAVIS, *City Engineer.*





## APPENDIX I.

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In the foregoing report and in that of Jan. 27, 1873 (City Doc. No. 29), it has been said that the *minimum yield*, or *the yield in a year of extreme drought*, should be used as the basis of estimates upon the real value of a source of supply ; also that " It has been customary in this country and in England to assume that a very large percentage of the rainfall may be made available ; but numerous failures to realize in times of even moderate drought the amount estimated upon, have led engineers to use a much smaller percentage than formerly."

In confirmation of these positions, and as showing the danger of calculating the available yield from *averages* of rainfalls, volumes of flow, etc., the following extracts from the report of the Royal Commission of 1867 on Water Supply, and from the evidence of engineers given before the Commission are printed.

In the report the term "gravitation schemes" is used as referring to schemes whose sources of supply are small rivers, improved with storage or catchment reservoirs, the water in most cases being delivered by gravitation, in distinction to schemes deriving a supply from large rivers, for which no storage basins are needed, and which usually require the water to be pumped for distribution.

### "REMARKS ON GRAVITATION SCHEMES GENERALLY.

" Durings the sittings of this Commission, the gravitation plans throughout the country have been subjected to a severe

test by the occurrence of an unusually long drought in 1868. Although the rainfall of the whole year was above the average, yet it was very unequally distributed; as from the end of April to the end of September, a period of five months, there was scarcely any rain. Hence the capacities of the catchment reservoirs were severely tested, the towns having to depend entirely on the stores in them, without any feeding supply, except that of perennial springs. . . .

"In Manchester, it appears that after official notices had been published, cautioning the inhabitants against waste, and urging them to economize their supplies, the corporation, on the 3d of August, limited the supply to the city to 12 hours of the day, stopped the street-watering, and diminished the trade supplies by one-half. They also made an arrangement with the mill-owners, for reducing by one-half the quantity given to the mills on the line of the river, and made compensation in money for the deficiency. In the middle of September the general supply to the town was further limited to eight hours per day, and the quantity for trades also diminished. Many persons were prosecuted for waste or undue use of water. The eight hours' supply lasted seven days, and the 12 hours' supply 76 days. . . .

"At Rochdale, as early as the 25th June, the supply was limited to four hours per day for 15 weeks; but with this precaution, during the second week in October, the store became entirely exhausted, and the town would have been almost without water, but that recourse was had to pumping from a colliery in the neighborhood.

"At Bury the store ran so low towards the end of August that it was reserved entirely for compensation to the mills, and the company obtained a supply of seven gallons per head from neighboring works; for baths, and for the numerous manufacturing and trade uses in the town, there was none. This continued for five weeks." . . .

The report further mentions the following towns depending

upon storage schemes, as having derived, during seasons of drought, a much less supply than had originally been estimated: Liverpool, Newcastle-on-Tyne, Bristol, Preston, Kendall, Bradford, Halifax, Sheffield, Stockport, Bolton, Ashton, Stalybridge, Oldham, Dewsbury, Warrington, Blackburn and others. . . .

"The causes of this difficulty may lie either in an over-estimate of the available rainfall, or in an insufficient provision of storage. The sufficiency of water-collecting plans in these respects must be tested both by the concurrence of several consecutive dry years, and by occasional droughts of long duration; and to obtain the necessary data on these points, for any particular district, must require special observations on that district, extended over a considerable time."

"In so variable a climate, and with a rainfall in different parts of the kingdom ranging in round numbers from 20 to 100 inches, it is of primary importance to have the most complete information as to the rainfall, and, as the annual variation is also great, the average fall for a term of years cannot be determined without observations extended over a long period. Less than 20 years would probably not suffice. But the question, with reference to a water-supply, has to deal not with the average rainfall of a long term of years, but with a short term depending on the capacity of the storage. In no case yet contemplated would it be prudent to rely on more than the average of three years, and under certain conditions it is doubtful whether two years would not be a safer term. . . .

"The question of storage room involves complicated considerations, which have been especially dwelt upon by Mr. Hawkesly. On account of the irregularity of the rainfall, particularly in mountainous districts, it is impracticable to construct reservoirs large enough to store the entire quantity received, so that all large floods occurring when the reservoirs are full must pass away and be lost. Hence the avail-

able average attainable from reservoirs must fall much short of that deduced simply from the fall of rain."

EVIDENCE OF ROBERT RAWLINSON, ESQ., CIVIL ENGINEER.

"Are we to understand that the object of the remarks which you have made with regard to the average of rainfall is to guard against the supposition that any scheme which professes to supply the inhabitants of any given town with water should not be calculated upon the average, but that there must be a deduction, and of, in your judgment, one third from that average as a proper deduction to make that quantity safe?

"I think so, the same as I say is exemplified in Liverpool; they have been landed in a very grievous mistake, because they relied upon the supposed average."

EVIDENCE OF REV. J. C. CLUTTERBUCK.

"Does there appear in your judgment any serious objection, apart from the question of cost, to the schemes which have been generally considered?

"One of the objections which struck me with regard to the scheme proposed by Mr. Bateman was, that he had not sufficiently shown that the water-shed there would yield the amount of water that he calculates upon. In the first place he has not sufficient information with reference to the average quantity of rainfall; not that I attach much importance to the averages of rainfall. I think that all rainfall with reference to the areas which are to supply water to London, must be considered with regard to the minimum, whatever that is — what shall be the minimum of rainfall, and what shall be the possible duration of drought which may deprive you of water at a certain time. The objection as it appears to me to Mr. Bateman's plan is that you have no certainty that you shall not at some period be deprived of water."



"Then your objection would be to taking an average at all?

"Decidedly.

"And for the sake of safety you would take the minimum fall, and all plus that would be gain?

"The only thing to set against that would be the natural or artificial storage of water in those lakes, but when you speak of that as a supply of water which you are to depend upon you must take the minimum, as it appears to me."

EVIDENCE OF THOMAS DUNCAN, ESQ., ENGINEER OF THE  
LIVERPOOL WATER WORKS.

"I think that calculations for the supply of towns should be upon minimums and not means." . . .

EVIDENCE OF THOMAS HAWKSLEY, ESQ., HYDRAULIC  
ENGINEER.

"In order to furnish that supply to London, what amount of rainfall would you consider to be necessary?

"I should first explain that the 45 inches of rain is only the quantity which on an average descends from the heavens, and that quantity is subject to two deductions. In the first place, we know as a matter of absolute fact that we cannot by any systems of reservoirs which it is practicable to construct ( I will not say with a reasonable but with a large amount of capital) deal with more than the average of three consecutive years of minimum fall. We know as a matter of experience — and this important fact is verified by large and long-continued rain tables — that in those three years the average fall of rain is almost precisely one-sixth part less than the general average, and I could refer the Commission to any number of long-continued rain tables to establish that fact; but we know also, as engineers, that practically that is the case. If we take from the 45 inches a sixth of that quantity, that will be  $7\frac{1}{2}$



inches, and that would leave  $37\frac{1}{2}$  inches as the quantity of rainfall due to the three minimum years. Then from that we have to take the evaporation. Now, the evaporation over a district like that, part of which is lowland and part of which is highland, will be about  $13\frac{1}{2}$  inches" [the evaporation and losses in the Eastern States of this country are from 75 to 100 per cent. greater than in England], "and if that be deducted there is the residual quantity of 24 inches, and that may be deemed to be the available quantity. That is the way in which we now make all our calculations for undertakings of this kind. I am not shifting or moving the calculation in any way. This system has been tested by actual results in a great many cases, and is known to be as accurate as anything dependent upon the eventualities of the seasons can possibly be. It is as near to the truth as we can in practice obtain anything. . . .

"You stated, did you not, that you allowed from the  $37\frac{1}{2}$  inches  $13\frac{1}{2}$  inches for evaporation?

"Yes;  $13\frac{1}{2}$  inches.

"That would give you an available rainfall of 24 inches?

"Yes, upon which you might, in my opinion, safely rely, providing your reservoirs were made large enough to deal with that quantity.

"What sized reservoirs should you think would be large enough to deal with that quantity?

"The reservoirs to deal with that quantity should be of a magnitude to store 170 days' supply."

EXTRACT FROM A REPORT TO THE COMMISSION, BY JOHN TAYLOR, ESQ., CIVIL ENGINEER, ON GRAVITATION WATER SUPPLIES TO LARGE TOWNS.

"The general conclusions to be drawn from the data I have given in the preceding pages respecting the largest gravitation water supplies in this country, are as follows:—

"That none of the works alluded to have completely fulfilled the anticipated results.

"Manchester and Glasgow are favorable examples of gravitation works, but exhibit signs of deficiency when tested for cycles of dry years; and of the *five* large towns alluded to, *four* have already erected, or are erecting, pumping works in aid of the gravitation supplies. . . .

"Thus, it appears that, basing calculations on *average* falls of rain is erroneous; the minimum quantities only should be depended upon; but, as I have before stated, there is yet no experience sufficient to show what are the minimum falls in a given district, nor what proportion of such falls would be available.

"The question of storage is, of course, an important element in gravitation works, and from past experience it is plain that complete security against want of water, in exceptionally dry years, could only be attained by storing all the flood waters of two or three successive winters, or, in other words, providing storage for 300 or 400 days' supply to the district.

"This matter was well explained by Mr. Homersham, C. E., in a report on the supply of water to Manchester in 1848, in which he states generally that if the whole quantity of water collected in wet years be not used, then the quantity of water that could be regularly yielded by the reservoirs would depend upon the depth of rain falling on the gathering ground and flowing off it in the *average* of years, since the water falling in wet years would be stored from wet to dry years. The size of such reservoirs must, however, be *very large*, as they must be sufficient to contain the superabundance of a succession of wet years, in order to compensate for the deficiency of a succession of dry ones.

"The axiom in mechanics that the strength of a beam is the strength only of its weakest part, applies also to gravitation water-works, their real strength or power of supply being only the *minimum quantity they may be reduced to.*"

EXTRACT FROM A REPORT OF JOHN TAYLOR, ESQ., ON THE  
DROUGHT OF 1868, AS REGARDS ITS EFFECT ON GRAVI-  
TATION WATER SUPPLIES TO LARGE TOWNS.

"With regard to the rainfall of the present year, the average for 13 localities in the counties of Lancashire, Cheshire, Cumberland, Northumberland, and Yorkshire, for the last 10 months, to the end of October, has been about 30 inches; and comparing the results of this year with the averages of the corresponding 10 months for many years past, at places for which I have been able to get such returns, I find the rainfall has been deficient in the proportion of about  $40\frac{1}{2}$  inches to  $34\frac{1}{2}$  inches, or 85 per cent. of the average. This deficiency, however, does not, in itself, altogether account for the extraordinary drought that has prevailed, because during the first three months of the present year the rainfall was generally more than an average. It was the singular deficiency of rain in May, June, and July, accompanied with an excess of temperature and evaporation, that caused the exhaustion of the springs, streams, rivers, and stores of water throughout the country.

"The general result has been that nearly all gravitation supplies of water, obtained from drainage grounds, have failed in a manner hitherto unprecedented within the known experience of such works, proving that the data on which they have been based have been fallacious, and that the storage reservoirs and gathering grounds of such works must be greatly increased to meet the demands of years like the present."

## APPENDIX II.

[FROM THE FIFTH ANNUAL REPORT OF THE STATE BOARD OF HEALTH.]

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ON THE PRESENT CONDITION OF CERTAIN RIVERS OF MASSACHUSETTS, TOGETHER WITH CONSIDERATIONS TOUCHING THE WATER-SUPPLY OF TOWNS. BY PROFESSOR WM. RIPLEY NICHOLS, OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.





## APPENDIX II.

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### ON THE PRESENT CONDITION OF CERTAIN RIVERS OF MASSACHUSETTS.

By an order of the Legislature, passed April 6, 1872, the Board of Health were instructed to inquire into certain matters connected with the questions of sewage, sewerage and the water-supply. The text of this order may be found on the tenth page of the last (fourth) Annual Report, and in compliance therewith a report upon these questions was made a year ago to the Board by Dr. Derby, Secretary of the Board, and the writer.

During the present year the inquiry has been prosecuted further, having more especially in view a reply to the third clause of the article referred to,—“the increasing joint use of water-courses for sewers and as a source of supply for domestic use by the people of this Commonwealth.”

It has been thought desirable to investigate the present condition of the running streams, partly to learn the extent to which they are now made the carriers and receptacles of refuse materials, and partly to put on record some detailed statements, to which future reference can be made in the event of apparently increasing contamination. This inquiry was begun last year on the Blackstone river, and this year has been made to embrace several of the rivers of Eastern Massachusetts, principally the Merrimack, Blackstone, Sudbury, Concord and Charles.

In endeavoring to ascertain the character of a natural water, and especially of a running stream, whether the ex-

amination be undertaken simply for scientific purposes or with reference to employing the water as a source of supply for domestic uses, it is important not to base too general statements upon the results of a single examination. The greater the number of conditions under which the samples can be taken, and the larger the number of samples, the more complete will be the answer to the inquiry proposed. Many loose statements find their way into reports of water committees and water boards, in which the estimate of the character of a running stream is based upon the results of a single examination, made, possibly, under extremely favorable or extremely unfavorable circumstances. It has therefore been thought better for the present year not to extend the work over a very large number of streams, but rather to choose a more limited number of streams, and to make examinations at several different times during the summer, fall and winter. It has been proposed further to examine the water at the same localities once or twice during the spring of 1874.

Great care has been exercised in collecting the water for chemical examination, and, having a very strong feeling of the importance of this part of the investigation, I have made personal visits to the localities indicated in the tables, and have taken the samples, except in one or two instances, with my own hands, using every necessary precaution.

The chemical examination of the waters was made as soon as possible after the collection, being, as a rule, begun and finished on the following day. A somewhat detailed statement of the methods employed will be found in the Appendix to this Report. Most of the analytical work has been performed by Miss Ellen H. Swallow, A. M., in the laboratory of the Massachusetts Institute of Technology, under my own direction. I take pleasure in acknowledging my indebtedness to her valuable assistance, and in expressing my confidence in the accuracy of the results obtained.

## THE MERRIMACK RIVER.

The Merrimack rises in New Hampshire. Its head-waters are the streams flowing from the granitic regions of the White and Franconia mountains; and Lake Winnipiseogee serves as a huge storage reservoir to equalize the flow of the river during the summer months. Of the 110 miles of its course, 40 are in our own State. Both in New Hampshire and in Massachusetts it receives contributions to its volume from almost innumerable brooks and small streams, and from other tributaries of considerable size, such as the Pemigewasset, Contoocook, Suncook, Souhegan, Nashua, Concord, Shawshine and Spicket. The manufacturing interest upon its banks is very great. Concord and Manchester (N. H.), and Lowell and Lawrence (Mass.) lie directly upon the river, taking advantage of its waters as a source of power, drawing from it in some cases their water-supply, and using it also as a means of removing a greater or less portion of the refuse from their factories and their dwellings. The population of the principal towns upon the river was as follows, according to the census of 1870:—

|            |   |   |   |   |   |        |
|------------|---|---|---|---|---|--------|
| Concord    | . | . | . | . | . | 12,241 |
| Manchester | . | . | . | . | . | 23,536 |
| Nashua     | . | . | . | . | . | 10,543 |
| Lowell     | . | . | . | . | . | 40,928 |
| Lawrence   | . | . | . | . | . | 28,921 |
| Haverhill  | . | . | . | . | . | 13,092 |

A few figures may give some idea of the extent of the manufacturing interest on the Merrimack within the borders of our own State. At Lowell there are some 75 mill-buildings, in which about 16,000 operatives are employed. About 10,000 horse-power is derived from the river, and, in addition, steam-power is used to the extent of 6,000 horse-power. The Merrimack Manufacturing Company alone consumes,

among other things, 7,500 gallons of oil per annum, 225,000 pounds of starch, 1,100 barrels of flour, 2,500,000 pounds of madder, 50,000 of copperas, 170,000 of alum, 200,000 of sumac, 1,120,000 of sulphuric acid, 300,000 of bark, 350,000 of soda-ash, and 40,000 of soap.\*

At Lawrence there are some 25 mills (buildings), employing 9,000 operatives. The manufacturing industry is less at Lawrence than at Lowell, but it is still very considerable. The Pacific Mills, which is the largest corporation, use some 800,000 pounds of starch, 540 barrels of flour, 8,300 gallons of oil, etc.†

### *Character of the River-Bed.*

The river, as has been said above, has its beginning in the mountain-streams of New Hampshire, and for the greater part of its course flows over a rocky or gravelly bed, the banks becoming in some places quite high. In the vicinity of Concord, N. H., there are beds of clay, and in times of freshet considerable quantities of earthy matter are washed into and carried down by the river. The water ordinarily is clear, and possesses little color. At times of freshet, however, for some two months and more during the year,‡ there is a large quantity of suspended matter, made up of particles

\* These figures are taken from the "Statistics of Lowell Manufactures, January, 1873," published by Stone & Huse, Lowell.

† "Statistics of Lawrence Manufactures, January, 1872." Published by Geo. S. Merrill & Co., Lawrence.

‡ The periods during which this state of turbidity exists are "not usually of long duration, perhaps never more than three or four weeks at a time. Observations made and records kept at the Pacific Mills show the amount of turbidity is in direct proportion to the height of water in the river, and that it exists to a troublesome degree only after the water reaches a certain height; while the records of the Essex Company, extending over a series of years, show that the total number of days in each year when the water is at or above that height is less than 90. — *Lawrence City Documents, 1872: Report on proposed Water-works, p. 31.*



of sand and silicious minerals and, to some extent, of clay. The aggregate amount of this earthy material is enormous. Dr. Dana, of Lowell, a number of years ago attempted to estimate it, but of course the data for any such calculation are far from being sufficient. He says:—

“In the year 1838, during 23 days of freshet, from May till November, no less than 71,874,063 pounds of geine [*i. e.* organic matter. — *W. R. N.*] and salts rolled by the city of Lowell, borne seaward. During the five days of the great freshet, from January 28th to February 1st, 1839, no less than 35,970,897 pounds of the same matter rolled by at from the rate of 112,128 pounds to 20,405,397 pounds per day; each cubic foot of water bearing onwards from  $1\frac{1}{2}$  to  $30\frac{1}{2}$  grains. This is only the suspended matter. That which is chemically dissolved by the waters, the fine, filmy deposit, which occurs in a few days after the coarser and grosser matters subside, and the matter ordinarily suspended in the water of the river, added to the above for the year 1838, give a grand total of 839,181 tons of salts and geine which were rolled down in the water of the Merrimack River.”\*

Dr. Dana made a chemical examination of the suspended matter, and states the composition of the coarser part, that which deposits more readily, to consist of—

|                         |   |   |                |
|-------------------------|---|---|----------------|
| Geine [organic matter]  | . | . | 3.92 per cent. |
| Silex . . . . .         | . | . | 72.70 “        |
| Oxide of iron . . . . . | . | . | 9.15 “         |
| Alumina . . . . .       | . | . | 8.30 “         |
| Lime . . . . .          | . | . | 0.51 “         |
| Magnesia . . . . .      | . | . | 0.10 “         |

Mr. Burbank, of Lowell, has more recently examined this suspended matter. He found that a portion settled very

\* A Muck Manual for Farmers, by Samuel A. Dana. 16mo. Lowell, 1843, p. 180.



rapidly, and consisted almost entirely of minute grains of fine, sharp sand; the portion of the deposit which settled after a longer interval of time was made up of finer sand, of scales of mica, of clay, of silicious infusorial remains, and of flocculent vegetable matter. The entire sediment from three gallons of river-water, taken April 29, 1869, and allowed to stand until it became perfectly clear, measured (wet)  $\frac{32}{100}$  of a cubic inch.

The character of the country from which the Merrimack gathers its supply, and the nature of its bed, would lead us to expect to find the water naturally quite free from organic impurities, and this expectation has been borne out by chemical examination.

#### *Present Condition of the River.*

The results of the chemical examinations of water from different points of the course of the river are given in Table I., in which table the results are stated in "parts per 100,000." As, however, it has been the custom with many to give such results in "grains per gallon," a second table (Ia.) is appended, in which they are so expressed.

The samples of water have been taken from the following localities:—

A. *Tyngsborough*, near the bridge now building, about eight miles above the dam at Lowell.

B. *Pawtucket Dam, Lowell*.—This dam is situated at the upper part of Lowell, just above the bridge which connects Lowell and Dracut. The dam diverts the water on the Lowell side into two canals belonging to the "Proprietors of the Locks and Canals on the Merrimack River." The canals convey the water to the various manufacturing corporations.

The heights of the water in the river at Lowell on the various days when examinations were made were as follows at 6.30 A. M. : —

|           |    |   |   |                                 |
|-----------|----|---|---|---------------------------------|
| July      | 10 | . | . | 2 feet 1 inch above top of dam. |
| September | 2  | . | . | 2 " 0 " "                       |
| "         | 8  | . | . | 2 " 2 inches above top of dam.  |
| "         | 10 | . | . | 2 " 0 " "                       |
| November  | 13 | . | . | 1 " 11 " "                      |
| December  | 31 | . | . | 2 " 3 " "                       |

Two or three weeks previous to the November examination there had been quite a freshet, owing to heavy rains. At this time, however, the amount of suspended matter was very small.

C. *Hunt's Falls*. — Just below Lowell the Merrimack is joined by the Concord, a stream small in comparison with the river into which it flows, but not of inconsiderable size. It furnishes power (in all about 500 horse-power) to several manufacturing establishments. Below the junction of the Concord and Merrimack are "Hunt's Falls," where the river flows rapidly over a bed strewn with boulders. The water at this point was of necessity taken near the shore. The current is rapid, however, even close to the banks, and samples were taken from both sides of the stream. As the factories are on the right-hand side of the river, and as the Concord enters on the same side, the character of the water is here very different at different parts of the current.

D. *Above Lawrence*. — From Hunt's Falls the river flows to Lawrence, where it encounters the dam of the Essex Company, and is thus diverted to furnish power to the various manufacturing establishments. The locality from which the

specimens were taken was about half a mile above the dam, near the boundary between Lawrence and Methuen and Andover. At this point the river is some 800 feet wide, and the depth of the water at different points was found to be as follows:—

|                                                   |   |          |
|---------------------------------------------------|---|----------|
| At a distance of about 100 feet from south shore, | . | 27 feet. |
| “ “ 200 “ “                                       | . | 37 “     |
| “ “ 400 “ “                                       | . | 36 “     |
| “ “ 600 “ “                                       | . | 23 “     |

E. *Below Lawrence.* — A short distance below Lawrence the canal which furnishes water to the larger corporations enters the river on the north side, and at about the same point the Spicket river also joins the Merrimack. The Spicket is a small stream. It receives drainage from some manufactories, and some sewage from dwellings. The canal on the south side of the river empties into the Shawshine river, which, in its turn, empties into the Merrimack somewhat below the mouth of the Spicket. The “station” chosen was below the mouth of the Spicket, and above that of the Shawshine. At this point the surface of the river is dotted over with bits of wool and cotton; the water is covered with a greasy film, and sometimes thickly strewn with flocks of soap-suds.

From what has been said of the magnitude of the manufacturing operations carried on upon the banks of the river (and nothing has been said of the very great number of paper-mills, grist-mills and small factories upon the numerous brooks and small streams which empty into the river), we might at first sight suppose that the effect would be to make the water very foul, and to cause it to be unfit to use for any domestic purpose. Inspection of the Tables I and Ia. (as well as of the Table Ib., in which are collected mean results)

will show that such is not the case; and if we observe the mean result of the examination of eleven samples taken from the river just below Lawrence, where to the eye it is the most filthy, we shall see that the amount of dissolved solid matter is very small.

TABLE I. — *Examination of Merrimack River.* [Results expressed in Parts per 100,000.]

| Number.          | DATE.                     | LOCALITY.                                  | Ammonia. | "Aluminoid"<br>Ammonia. | SOLID RESIDUE OF FILTERED<br>WATER. |                             |        | Chlorine. | Oxygen, cubic<br>centimeters to<br>the liter. | Temperature<br>in centigrade<br>degrees. |
|------------------|---------------------------|--------------------------------------------|----------|-------------------------|-------------------------------------|-----------------------------|--------|-----------|-----------------------------------------------|------------------------------------------|
|                  |                           |                                            |          |                         | Inor-<br>ganic.                     | Organic<br>and<br>Volatile. | Total. |           |                                               |                                          |
| 187              | Thursday, Nov. 13, '73.   | { Tyngsborough, . . }                      | 0.0044   | 0.0113                  | 2.40                                | 1.78                        | 4.18   | 0.16      | ..                                            | ..                                       |
| 188              | " "                       |                                            | 0.0044   | 0.0113                  | 3.56                                | 1.44                        | 5.00   | 0.14      | ..                                            | ..                                       |
| 65 <sup>1</sup>  | Thursday, July 10, '73.   | { Lowell, above Paw-<br>tucket dam, . . }  | 0.0043   | 0.0091                  | 2.24                                | 1.72                        | 3.96   | 0.14      | ..                                            | ..                                       |
| 66 <sup>1</sup>  | " "                       |                                            | 0.0048   | 0.0091                  | 2.96                                | 1.68                        | 4.64   | 0.14      | ..                                            | ..                                       |
| 101 <sup>2</sup> | Tuesday, Sept. 2, '73.    |                                            | 0.0047   | 0.0153                  | 1.76                                | 2.32                        | 4.08   | 0.14      | ..                                            | ..                                       |
| 108 <sup>3</sup> | Monday, Sept. 8, '73.     |                                            | 0.0060   | 0.0150                  | 2.08                                | 1.84                        | 3.92   | 0.16      | 2.32                                          | ..                                       |
| 120 <sup>4</sup> | Wednesday, Sept. 10, '73. | { Lowell, above Paw-<br>tucket dam, . . }  | 0.0047   | 0.0104                  | 1.56                                | 1.44                        | 3.00   | 0.10      | 1.84                                          | 20.0                                     |
| 121 <sup>5</sup> | " "                       |                                            | 0.0044   | 0.0100                  | 1.80                                | 1.84                        | 3.64   | 0.12      | ..                                            | ..                                       |
| 122 <sup>6</sup> | " "                       |                                            | 0.0045   | 0.0111                  | 1.60                                | 1.96                        | 3.56   | 0.12      | ..                                            | ..                                       |
| 189 <sup>6</sup> | Thursday, Nov. 13, '73.   |                                            | 0.0040   | 0.0131                  | 3.60                                | 0.96                        | 4.56   | 0.14      | ..                                            | ..                                       |
| 207 <sup>7</sup> | Thursday, Jan. 1, '74.    | { Under Central Bridge,<br>Lowell, . . . } | 0.0053   | 0.0100                  | 2.48                                | 2.00                        | 4.48   | 0.20      | ..                                            | ..                                       |
| 67 <sup>8</sup>  | Thursday, July 10, '73.   |                                            | 0.0051   | 0.0113                  | 2.08                                | 1.68                        | 3.76   | 0.16      | ..                                            | ..                                       |
| 68 <sup>9</sup>  | " "                       |                                            | 0.0040   | 0.0087                  | 2.60                                | 1.40                        | 4.00   | 0.16      | ..                                            | ..                                       |
| 69 <sup>10</sup> | " "                       |                                            | 0.0044   | 0.0098                  | 4.64                                | 1.44                        | 6.08   | 0.16      | ..                                            | ..                                       |
| 70 <sup>11</sup> | " "                       |                                            | 0.0053   | 0.0117                  | 3.84                                | 1.92                        | 5.76   | 0.16      | ..                                            | ..                                       |
| 71 <sup>12</sup> | " "                       |                                            | 0.0040   | 0.0090                  | 3.80                                | 1.16                        | 4.96   | 0.18      | ..                                            | ..                                       |



|                   |                           |                         |        |        |      |      |      |      |                    |      |
|-------------------|---------------------------|-------------------------|--------|--------|------|------|------|------|--------------------|------|
| 109 <sup>13</sup> | Monday, Sept. 8, '73,     |                         | 0.0073 | 0.0289 | 3.40 | 3.08 | 6.48 | 0.28 | 1.89               | ..   |
| 110 <sup>13</sup> | "                         | Below Lowell, at        | 0.0047 | 0.0247 | 2.76 | 3.32 | 6.08 | 0.24 | ..                 | ..   |
| 125 <sup>13</sup> | Wednesday, Sept. 10, '73, | Hunt's Falls, right-    | 0.0047 | 0.0206 | 3.16 | 2.64 | 5.80 | 0.22 | ..                 | ..   |
| 126 <sup>13</sup> | "                         | hand side of river.     | 0.0049 | 0.0240 | 3.20 | 2.80 | 6.00 | 0.22 | ..                 | ..   |
| 190 <sup>13</sup> | Thursday, Nov. 13, '73,   |                         | 0.0044 | 0.0347 | 4.35 | 3.64 | 8.00 | 0.38 | ..                 | ..   |
| 111 <sup>13</sup> | Monday, Sept. 8, '73,     | Same locality, on left- | 0.0020 | 0.0165 | 2.16 | 1.88 | 4.04 | 0.14 | ..                 | ..   |
| 123 <sup>13</sup> | Wednesday, Sept. 10, '73, | hand side of stream,    | 0.0031 | 0.0143 | 2.20 | 1.72 | 3.92 | 0.14 | ..                 | ..   |
| 124 <sup>13</sup> | "                         |                         | 0.0020 | 0.0127 | 2.08 | 1.80 | 3.88 | 0.18 | ..                 | ..   |
| 114 <sup>14</sup> | Tuesday, Sept. 9, '73,    |                         | 0.0030 | 0.0105 | 2.20 | 2.00 | 4.20 | 0.20 | 1.81               | 20.5 |
| 115 <sup>15</sup> | "                         |                         | 0.0044 | 0.0117 | 2.40 | 1.56 | 3.96 | 0.20 | 1.73               | 20.5 |
| 131 <sup>16</sup> | Friday, Sept. 12, '73,    |                         | 0.0073 | 0.0121 | 2.00 | 1.40 | 3.40 | 0.20 | ..                 | ..   |
| 132 <sup>17</sup> | "                         |                         | 0.0057 | 0.0113 | 2.00 | 2.20 | 4.20 | 0.20 | ..                 | ..   |
| 145 <sup>18</sup> | Thursday, Sept. 18, '73,  | Lawrence, above the     | 0.0040 | 0.0127 | 2.20 | 1.40 | 3.60 | 0.20 | 1.79 <sup>20</sup> | 19.5 |
| 146 <sup>19</sup> | "                         | dam . . . .             | 0.0040 | 0.0107 | 2.16 | 1.48 | 3.61 | 0.20 | ..                 | ..   |
| 147 <sup>21</sup> | "                         |                         | 0.0049 | 0.0127 | 2.80 | 1.60 | 4.40 | 0.20 | 2.05               | 19.0 |
| 148 <sup>22</sup> | "                         |                         | 0.0037 | 0.0100 | 2.92 | 1.60 | 4.52 | 0.20 | ..                 | ..   |
| 163 <sup>23</sup> | Thursday, Sept. 25, '73,  |                         | 0.0043 | 0.0087 | 2.80 | 1.80 | 4.60 | 0.18 | 3.20 }<br>3.15 }   | 18.0 |

1 Entrance to new canal. At surface.  
2 Opposite Inlet-chamber, 100 feet from shore. The unfiltered water gave, inorganic, 2.40; organic, 2.40; total, 4.80.  
3 Entrance to new canal. Strong wind blowing.  
4 Opposite Inlet-chamber. At surface.  
5 Opposite Inlet-chamber, 6 feet below surface.  
6 Entrance to new canal.  
7 Taken by Gen. E. Evans. 7 feet below surface.  
8 Under centre of left-hand span. 11-12 feet below surface.  
9 Under centre of left-hand span. 6 feet below surface.  
10 Taken about one-eighth mile above dam. This sample was taken from the shore.  
11 Under centre of middle span, 6 feet below surface.  
12 Under centre of middle span. 10-12 feet below surface.  
13 These samples were taken from the shore.  
14 Under centre of middle span, 6 feet below surface.  
15 Taken about one-eighth mile above dam. Middle of river.  
16 Just above dam. Middle of stream.  
17 Taken about one-half mile above dam. Middle of river.  
18 One-half mile above dam. About 20 feet from south shore.  
19 Two other determinations in the middle of the stream, made at localities but slightly removed from each other, gave 1.82 c.c. and 1.81 c.c., respectively, at temperature of 74-25° C.  
20 Two other determinations in the middle of the stream, made at localities but slightly removed from each other, gave 1.82 c.c. and 1.81 c.c., respectively, at temperature of 74-25° C.  
21 Just above dam. Middle of stream. 12 feet below surface.  
22 Just above dam. About 200 feet from north shore. 6 feet below.

23 Same as No. 146.

TABLE I. — *Examination of Merrimack River.* — (Continued.)

| Number.        | DATE.                     | LOCALITY.                                                        | Ammonia.         | "Albunoid."      | SOLID RESIDUE OR FILTERED WATER. |                             |              | Chlorine.    | Oxygen, cubic centimeters to the liter. | Temperature in centigrade degrees. |
|----------------|---------------------------|------------------------------------------------------------------|------------------|------------------|----------------------------------|-----------------------------|--------------|--------------|-----------------------------------------|------------------------------------|
|                |                           |                                                                  |                  |                  | Inor-<br>ganic.                  | Organic<br>and<br>Volatile. | Total.       |              |                                         |                                    |
| 1614           | Thursday, Sept. 25, '73.  | Lawrence, above the<br>dam,                                      | 0.0043           | 0.0087           | 2.76                             | 1.64                        | 4.40         | ..           | ..                                      | ..                                 |
| 1625           | " "                       |                                                                  | 0.0040           | 0.0117           | 2.28                             | 1.68                        | 3.96         | 0.16         | 3.16                                    | 18.0                               |
| 16620          | " "                       |                                                                  | 0.0040           | 0.0117           | 2.36                             | 1.88                        | 4.24         | 0.16         | ..                                      | ..                                 |
| 12757          | Friday, Sept. 12, '73,    | Below Lawrence, just<br>above the mouth of<br>the Shawshine riv. | 0.0051           | 0.0147           | 2.56                             | 2.04                        | 4.60         | 0.20         | ..                                      | ..                                 |
| 12838          | " "                       |                                                                  | 0.0029           | 0.0120           | 2.20                             | 1.76                        | 3.96         | 0.16         | ..                                      | ..                                 |
| 12920          | " "                       |                                                                  | 0.0033           | 0.0137           | 1.80                             | 1.60                        | 3.40         | 0.16         | ..                                      | ..                                 |
| 15050          | Thursday, Sept. 18, '73.  | Between Lawrence<br>and Haverhill, . . .                         | 0.0024           | 0.0100           | 2.60                             | 1.96                        | 4.56         | 0.20         | ..                                      | ..                                 |
| 151 }<br>152 } | " "<br>" "                |                                                                  | 0.0040<br>0.0035 | 0.0140<br>0.0148 | 2.36<br>3.16                     | 1.84<br>2.04                | 4.20<br>5.20 | 0.20<br>0.20 | ..<br>..                                | ..<br>..                           |
| 16732          | Thursday, Sept. 25, '73.  |                                                                  | 0.0027           | 0.0150           | 2.96                             | 1.86                        | 4.82         | 0.16         | 3.30                                    | ..                                 |
| 16823          | " "                       |                                                                  | 0.0013           | 0.0110           | 3.16                             | 1.24                        | 4.40         | 0.16         | ..                                      | ..                                 |
| 16954          | " "                       |                                                                  | 0.0020           | 0.0120           | 2.68                             | 1.76                        | 4.44         | 0.16         | ..                                      | ..                                 |
| 117            | Wednesday, Sept. 10, '73, |                                                                  | 0.0026           | 0.0101           | 2.72                             | 2.08                        | 4.80         | ..           | ..                                      | ..                                 |
| 118            | " "                       |                                                                  | 0.0040           | 0.0127           | 2.84                             | 2.00                        | 4.84         | 0.18         | 1.74                                    | ..                                 |

24 Sample No. 143. 6 feet below dam. 25 Sample No. 145. 12 feet below dam. 26 Sample No. 146. 12 feet below dam. 27 Taken near right bank above. 11 feet above dam. 28 Taken near middle of stream. 29 Taken near left bank above. 30 About 200 feet from mouth of river. 31 Taken at 6.5 mile point above mouth of river. 32 About 250 feet from mouth of river. 33 About 250 feet from mouth of river. 34 About 250 feet from mouth of river.

TABLE Ia. — *Examination of Merrimack River.*

[Results expressed in Grains per U. S. Gallon.]

| Number. | DATE.           | LOCALITY.                              | Ammonia. | "Albuminoid"<br>Ammonia. | SOLID RESIDUE OF FILTERED<br>WATER. |                             |        | Chlorine. | Oxygen, cubic<br>Inches to the<br>Gallon. | Temperature in<br>degrees Fahr. |
|---------|-----------------|----------------------------------------|----------|--------------------------|-------------------------------------|-----------------------------|--------|-----------|-------------------------------------------|---------------------------------|
|         |                 |                                        |          |                          | Inorganic                           | Organic<br>and<br>Volatile. | Total. |           |                                           |                                 |
| 187 1   | 1873 — Nov. 13, | Tyngsborough, . .                      | 0.0025   | 0.0066                   | 1.40                                | 1.04                        | 2.44   | 0.09      | ..                                        | ..                              |
| 188     | " "             |                                        | 0.0026   | 0.0066                   | 2.08                                | 0.84                        | 2.92   | 0.08      | ..                                        | ..                              |
| 65      | July 10,        |                                        | 0.0025   | 0.0053                   | 1.31                                | 1.00                        | 2.31   | 0.08      | ..                                        | ..                              |
| 66      | " "             |                                        | 0.0028   | 0.0053                   | 1.73                                | 0.98                        | 2.71   | 0.08      | ..                                        | ..                              |
| 101 2   | Sept. 2,        | Lowell, above Paw-<br>tucket Dam, . .  | 0.0027   | 0.0089                   | 1.03                                | 1.35                        | 2.38   | 0.08      | ..                                        | ..                              |
| 108     | 8,              |                                        | 0.0035   | 0.0089                   | 1.21                                | 1.07                        | 2.28   | 0.09      | 0.77                                      | ..                              |
| 120     | 10,             |                                        | 0.0027   | 0.0060                   | 0.91                                | 0.84                        | 1.75   | 0.06      | 0.43                                      | 68.0                            |
| 121     | " "             |                                        | 0.0026   | 0.0058                   | 1.05                                | 1.07                        | 2.12   | 0.07      | ..                                        | ..                              |
| 122     | " "             | Nov. 13,                               | 0.0025   | 0.0065                   | 0.93                                | 1.14                        | 2.07   | 0.07      | ..                                        | ..                              |
| 189     | Nov. 13,        |                                        | 0.0023   | 0.0076                   | 2.10                                | 0.56                        | 2.66   | 0.08      | ..                                        | ..                              |
| 207     | 1874 — Jan. 1,  |                                        | 0.0031   | 0.0058                   | 1.45                                | 1.17                        | 2.62   | 0.12      | ..                                        | ..                              |
| 67      | 1873 — July 10, |                                        | 0.0030   | 0.0066                   | 1.21                                | 0.98                        | 2.19   | 0.09      | ..                                        | ..                              |
| 68      | " "             | Under Central Bridge,<br>Lowell, . . . | 0.0023   | 0.0051                   | 2.52                                | 0.81                        | 2.33   | 0.09      | ..                                        | ..                              |
| 69      | " "             |                                        | 0.0026   | 0.0054                   | 2.71                                | 0.84                        | 3.55   | 0.09      | ..                                        | ..                              |
| 70      | " "             |                                        | 0.0031   | 0.0068                   | 2.24                                | 1.12                        | 3.36   | 0.09      | ..                                        | ..                              |
| 71      | " "             |                                        | 0.0023   | 0.0047                   | 2.21                                | 0.68                        | 2.89   | 0.10      | ..                                        | ..                              |

1 For remarks see Table I.

2 The unfiltered water gave: inorganic, 1.17; organic, 1.40; Total, 2.57.

TABLE Ia. — *Examination of Merrimack River* — (Continued.)

| Number. | DATE.         | LOCALITY.             | Ammonia. | "Albuminoid"<br>Ammonia. | SOLID RESIDUE OF FILTERED<br>WATER. |                             |        | Chlorine. | Oxygen, cubic<br>inches, to the<br>gallon. | Temperature in<br>degrees Fahr. |
|---------|---------------|-----------------------|----------|--------------------------|-------------------------------------|-----------------------------|--------|-----------|--------------------------------------------|---------------------------------|
|         |               |                       |          |                          | Inorganic                           | Organic<br>and<br>Volatile. | Total. |           |                                            |                                 |
| 109     | 1873—Sept. 8, |                       | 0.0043   | 0.0168                   | 1.98                                | 1.80                        | 3.78   | 0.16      | 0.44                                       | .                               |
| 110     | "             |                       | 0.0028   | 0.0144                   | 1.61                                | 1.94                        | 3.55   | 0.14      | .                                          | .                               |
| 125     | 10,           | Hunt's Falls, Lowell, | 0.0028   | 0.0120                   | 1.85                                | 1.54                        | 3.39   | 0.13      | .                                          | .                               |
| 126     | "             | right-hand side,      | 0.0029   | 0.0140                   | 1.87                                | 1.63                        | 3.50   | 0.13      | .                                          | .                               |
| 190     | Nov. 13,      |                       | 0.0026   | 0.0203                   | 2.55                                | 2.12                        | 4.67   | 0.22      | .                                          | .                               |
| 111     | Sept. 8,      |                       | 0.0012   | 0.0096                   | 1.26                                | 1.10                        | 2.36   | 0.08      | .                                          | .                               |
| 123     | 10,           | Hunt's Falls, left-   | 0.0018   | 0.0083                   | 1.28                                | 1.00                        | 2.28   | 0.08      | .                                          | .                               |
| 121     | "             | hand side,            | 0.0012   | 0.0074                   | 1.21                                | 1.05                        | 2.26   | 0.10      | .                                          | .                               |
| 114     | 9,            |                       | 0.0018   | 0.0088                   | 1.28                                | 1.17                        | 2.45   | 0.12      | 0.42                                       | 68.9                            |
| 115     | "             |                       | 0.0026   | 0.0068                   | 1.40                                | 0.91                        | 2.31   | 0.12      | 0.40                                       | 68.0                            |
| 131     | 12,           |                       | 0.0043   | 0.0071                   | 1.17                                | 0.82                        | 1.99   | 0.12      | .                                          | .                               |
| 132     | "             |                       | 0.0033   | 0.0066                   | 1.17                                | 1.30                        | 2.47   | 0.12      | .                                          | .                               |
| 145     | 18,           | Lawrence, above       | 0.0025   | 0.0074                   | 1.28                                | 0.82                        | 2.10   | 0.12      | 0.41                                       | 67.0                            |
| 146     | "             | dam,                  | 0.0023   | 0.0062                   | 1.26                                | 0.83                        | 2.12   | 0.12      | .                                          | .                               |
| 147     | 18,           |                       | 0.0023   | 0.0070                   | 1.63                                | 0.93                        | 2.56   | 0.12      | 0.47                                       | 66.2                            |
| 148     | "             |                       | 0.0022   | 0.0058                   | 1.70                                | 0.93                        | 2.63   | 0.12      | .                                          | .                               |

|     |                |   |   |   |                   |        |      |      |      |      |      |      |
|-----|----------------|---|---|---|-------------------|--------|------|------|------|------|------|------|
| 163 | 1873—Sept. 25, | . | . | . | .                 | 0.0051 | 1.63 | 1.05 | 2.68 | 0.11 | 0.74 | 64.4 |
| 164 | "              | . | . | . | Lawrence, above   | 0.0051 | 1.61 | 0.96 | 2.57 | .    | .    | .    |
| 165 | "              | . | . | . | dam, . . .        | 0.0068 | 1.33 | 0.98 | 2.31 | 0.09 | 0.73 | 64.4 |
| 166 | "              | . | . | . | .                 | 0.0068 | 1.38 | 1.10 | 2.48 | 0.09 | .    | .    |
| 127 | 12,            | . | . | . | .                 | 0.0086 | 1.49 | 1.19 | 2.68 | 0.12 | .    | .    |
| 128 | "              | . | . | . | .                 | 0.0070 | 1.28 | 1.03 | 2.31 | 0.09 | .    | .    |
| 129 | "              | . | . | . | .                 | 0.0080 | 1.05 | 0.93 | 1.98 | 0.09 | .    | .    |
| 160 | 18,            | . | . | . | .                 | 0.0058 | 1.52 | 1.14 | 2.66 | 0.12 | .    | .    |
| 161 | "              | . | . | . | .                 | 0.0082 | 1.38 | 1.07 | 2.45 | 0.12 | .    | .    |
| 162 | "              | . | . | . | Below Lawrence, . | 0.0086 | 1.84 | 1.19 | 3.03 | 0.12 | .    | .    |
| 167 | 25,            | . | . | . | .                 | 0.0087 | 1.73 | 0.79 | 2.52 | 0.09 | 0.76 | .    |
| 168 | "              | . | . | . | .                 | 0.0064 | 1.85 | 0.72 | 2.57 | 0.09 | .    | .    |
| 169 | "              | . | . | . | .                 | 0.0070 | 1.56 | 1.03 | 2.59 | 0.09 | .    | .    |
| 117 | 10,            | . | . | . | .                 | 0.0015 | 1.69 | 1.21 | 2.80 | .    | .    | .    |
| 118 | "              | . | . | . | .                 | 0.0023 | 1.66 | 1.17 | 2.83 | 0.11 | 0.40 | .    |

<sup>1</sup>Two other determinations (see Table I.) gave 0.427 and 0.423 cubic inches, respectively.



TABLE Ib.

|                           | PARTS PER 100,000.                            |                                                 |                                                 | GRAINS PER U. S. GALLON.                      |                                                 |                                                 |
|---------------------------|-----------------------------------------------|-------------------------------------------------|-------------------------------------------------|-----------------------------------------------|-------------------------------------------------|-------------------------------------------------|
|                           | Mean of 11 Exam-<br>inations above<br>Lowell. | Mean of 12 Exam-<br>inations above<br>Lawrence. | Mean of 11 Exam-<br>inations below<br>Lawrence. | Mean of 11 Exam-<br>inations above<br>Lowell. | Mean of 12 Exam-<br>inations above<br>Lawrence. | Mean of 11 Exam-<br>inations below<br>Lawrence. |
| Ammonia, . . . . .        | 0.0047                                        | 0.0044                                          | 0.0031                                          | 0.0027                                        | 0.0026                                          | 0.0018                                          |
| "Albuminoid Ammonia,"     | 0.0114                                        | 0.0110                                          | 0.0127                                          | 0.0066                                        | 0.0064                                          | 0.0074                                          |
| Inorganic, . . . . .      | 2.37                                          | 2.41                                            | 2.64                                            | 1.38                                          | 1.41                                            | 1.54                                            |
| Organic and volatile, . . | 1.73                                          | 1.69                                            | 1.79                                            | 1.01                                          | 0.98                                            | 1.05                                            |
| Total solid matter, . . . | 4.10                                          | 4.10                                            | 4.43                                            | 2.39                                          | 2.39                                            | 2.59                                            |
| Chlorine, . . . . .       | 0.14                                          | 0.20                                            | 0.18                                            | 0.08                                          | 0.12                                            | 0.11                                            |

What becomes of all the waste material daily thrown into the waters of the Merrimack?

This question has already been somewhat discussed in a previous report, but it may be well to recapitulate or restate the facts and opinions there brought forward.

The principal causes which contribute to the apparent disappearance of the refuse received by the river are three, and these, in what I conceive to be the inverse order of their importance, are oxidation, deposition and dilution.

*Oxidation.* — Although it is not practicable, in the case of a running stream like the Merrimack, to trace the progress of the destruction of the organic material by oxidation, yet there is no doubt that a certain amount is so destroyed. The presence of nitrogen in the form of nitrites and nitrates is mainly due to the oxidation of nitrogenous organic material. The amount of nitrogen thus existing in the Merrimack, even below Lawrence, is so small that its determination would not afford much that is valuable as data of comparison. In the last report of the Board, the reasons are given which lead to

the belief that the effects of oxidation have been overrated, although they are not, on the other hand, to be depreciated. In this connection I made an attempt to ascertain whether any difference could be perceived in the amount of oxygen dissolved in the water at various points in the stream, such as above and below Lawrence and above and below Lowell. The results obtained may be found in the Tables I. and I. *a*. As far as the direct end which was in view when the inquiry began is concerned, the results are negative. It is true that on September 8th the amount of oxygen in the river above Lowell (see No. 108) was found to be 3.32 cubic centimeters to the liter, while below the city (No. 109) only 1.89 cubic centimeters was found; but determinations made at other times showed a smaller amount above the dam; and, moreover, at the time No. 108 was examined, a stiff breeze was ruffling the surface of the river. Although a very considerable number of determinations, made at frequent intervals over a sufficiently long period of time, might show some decrease of oxygen below the manufacturing towns, I did not feel that sufficient encouragement was afforded by the results obtained to warrant, at the present time, a very extended series of experiments. The total amount of oxygen seems very small, — much smaller than we might expect. Moreover, the amount was found to be quite uniform throughout the mass of the water, as may be seen by comparing Nos. 145 and 147, where water was taken not only from the surface, but also from a depth of some twelve feet.

*Deposition.* — Much waste material thrown into rivers is made up wholly or in part of substances insoluble in water. A portion, and a very considerable portion, even in a running stream, is deposited upon the bottom or stranded upon the banks. This deposition can often be very plainly observed in the immediate neighborhood of the points of discharge. Other chemical changes besides that of oxidation, alluded to

above, take place, especially where the refuse is that from manufactories. Waste liquors from different manufacturing operations meet and cause the formation of new and, in many cases, of insoluble compounds. At the time of the spring freshets, much that during the summer may have been deposited at one part of the stream, in the bed or on the banks, is washed up again, and, mingling with the earthy materials held in suspension, is swept onward to the sea, or, enveloped in the earthy matter, especially if this be of a clayey nature, is deposited lower down on the stream. This scouring action of freshets is, in fact, relied upon to keep the bed of the river clear in certain cases where a so-called *natural filtration* is adopted as a means of improving the quality of river-water which is to be used as a supply for domestic use.

*Dilution.* — By far the most important reason of the apparent disappearance of sewage and other waste material is the fact that the amount of solid matter is so small compared with the volume of water into which it is thrown, that it is disseminated through the mass, and thus lost to observation, and, in many cases, to chemical tests.

If, in the examination of the Merrimack made at two such localities as above Lowell and then again below Lawrence, we find at the lower point no sensible increase of organic matter in a given bulk of water, the first explanation that suggests itself is, that the organic matter is so rapidly destroyed by oxidation as to leave no sign. A comparison of the results obtained in the chemical examination of the river above and below Lawrence may be instructive in this connection. Between these two points the river receives the refuse from nearly all the manufacturing establishments, a large proportion of the excreta of the factory operatives, and a portion of the sewage of Lawrence. Moreover, the lower station is so short a distance below the city, that no chemist, probably, would believe that any considerable

destruction of organic matter could take place in the rapid flow for so short a distance, and if, from chemical grounds, the evidence was not sufficient, the floating soap-suds, with still unbroken bubbles, and other materials borne down upon the current show the same thing. Now, in spite of this addition, we observe only a slight increase in the total solid residue and in the albuminoid matters, while in the *chlorine* there is an actual decrease. This last fact is of considerable significance. I regard the determination of chlorine to be of great utility. All natural waters contain a small proportion of chlorine, very small in inland waters, slightly increased in waters near the sea. Chlorine is a universal accompaniment of sewage, generally in the form of chloride of sodium (common salt), and occurs also in most manufacturing refuse. All the chlorine used in the process of bleaching is eventually washed away, and that contained in the various compounds of this element which are used in dye-houses and print-works, finds its way in the end into the drains of the establishments. On this account, although harmless in the combinations in which it exists, its presence indicates the presence, now or formerly, of refuse material. Of course, in regions containing salt-springs and salt deposits these statements would not hold good, but our rivers normally contain but a very small proportion of chlorine. It is to be remarked further, that most chlorides are quite soluble in water, and that the chlorine compounds would have no tendency to deposit in an insoluble state,\* so that, in a running stream, I do not see that there could be any sensible decrease except as a result of dilution.

Now, although a large quantity of chlorine compounds are

\* It is, of course, true that there are insoluble substances which contain chlorine but there would be no opportunity for the formation of such. It is also asserted that natural soils and earth-filters will retain or absorb even soluble chlorides; if this be so, it could not, in any way, cause a decrease of the amount of chlorides in a running stream.



being thrown into the river at Lawrence, yet there is no apparent increase of the proportion of chlorine in the water below the city. In this case we have a substance readily traced. The chlorine cannot escape from the river in gaseous form, nor does it deposit in insoluble combination, and yet the first inspection of the analytical results would lead, perhaps, to the conclusion that there was no real increase of impurity. From these considerations it is evident, that in the case of the soluble *organic matter* it is not necessary to suppose any destruction or decomposition; the apparent decrease or lack of increase may be explained, as in the case of chlorine, by the fact of dilution, and where the distance between the two points of examination is so short as in the instance now under discussion (above and below Lawrence), this is no doubt the main cause concerned.

In connection with this statement in reference to the chlorine, I was led to make an estimate of the amount of this element actually cast into the river at Lowell and Lawrence. To this end circulars were sent to the principal corporations in these cities asking for information with regard to the amount of chlorine-containing substances actually used by them. From these replies, it would seem that from the manufacturing operation at Lowell, chlorine to the amount of 300,000 pounds annually finds its way into the river. The refuse of household operations and excremental matter which reaches the river may probably with safety be estimated to add as much as 400,000 pounds, making the total amount from Lowell 700,000 pounds. At Lawrence the amount derived from manufacturing operations may be taken as 500,000 pounds; from other sources, 300,000 pounds; in all, 800,000 pounds. Although this amount seems quite large, it is to be observed that in the river it becomes mixed with an enormous amount of water, and, indeed, the total amount of waste material thrown into the Merrimack is small compared with the great volume of water. I have been led, in



fact, to make a calculation which shows that, if we take the average summer flow of the Merrimack at Lowell as being about 2,100 cubic feet per second,\* in order to increase the solid matter in solution by the amount of one grain to the gallon, it would be necessary that there should be thrown into the river as much as 100 tons of *dry* material daily. This leaves out of the account the *insoluble* matters, and supposes the volume of water to remain the same; but as the volume of water is continually increasing, and as the soluble matter would be accompanied by a large amount of insoluble substances, a very much greater quantity would be necessary in order to cause such an increase as has been mentioned. When we consider that much of bulk of what we see cast into the stream is water, containing only a small proportion of solid matter, it will not surprise us that more effect is not produced upon the river. For example, urine contains only about 4 per cent. of solid matter, fæces only about 27 to 30 per cent., and I found last year that the mean amount of dissolved solids in Boston day-sewage was only six one-hundredths of one per cent. (0.06 per cent).†

The waste liquors from many manufacturing operations are also quite dilute; and although sometimes the stream into

\* Various estimates have been made of the amount of water flowing in the Merrimack at Lowell. I have taken, as sufficiently reliable, the mean summer flow at 2,100 cubic feet, and the mean annual flow as 5,400 cubic feet per second. The amount of water brought down by the Concord river has never been estimated with any attempt at accuracy. I am informed by the treasurer of the Wamesit Power Company, which controls the water-power on this river, that an estimate of the flow in summer was made some years ago for mill purposes. This estimate was 288 cubic feet per second. At Lawrence the power is controlled by the Essex Company. The statements which I have been able to obtain as to the amount of water are as follows: the day-flow varies from 4,000 to 40,000 cubic feet, and in extreme floods reaches 90,000 cubic feet per second. The minimum flow (4,000 cubic feet) usually continues for about three months, but has continued for six months, as, for instance, in 1870. In the dry season the night-flow is about 4,000 cubic feet per second.

† See Fourth Annual Report of State Board of Health, 1873, p. 71.

which the refuse is poured is colored for a considerable distance, yet the actual amount of solid coloring matter may not be very large.

In addition to what has just been said, if we, instead of considering the summer flow of 2,100 cubic feet, take the mean flow, which is some 5,400 cubic feet per second, or the flow during a freshet, — as, for instance, when the water has a depth of nine or ten feet over the Lawrence dam, we shall see that dilution alone is sufficient to account for the slight apparent effect of the discharge into the stream of much that is offensive and noxious.

Although the waste material thrown into the river is so largely diluted as to be almost lost to observation, we might be able to determine the increase of impurity between two points, if the amount of water at the points in question could be accurately gauged. But even in this case it would not be possible to infer too closely the amount to be attributed to any given source, for the river is continually receiving accessions to its volume by the infiltration of water from the surrounding country. Moreover, water is continually sinking through the bed of the river, and either through actual crevices in the rocky bed, or by a more slow process of percolation where the bed is gravelly, more or less water is finding its way to lower strata.

The relative amounts in this way lost and gained vary very much in different streams, the loss or gain being in some cases readily observed, but in some cases going on without observation. Thus the rigid scientific investigation of the amount of impurities carried down by a stream, and the increase or decrease of these impurities owing to natural or artificial causes, would be a very difficult problem. Most practical ends are, however, met by a knowledge of the proportional amount of impurity at any given point. As will be seen by the results of the chemical examinations, this proportion in the Merrimack is not large. The only thing which

TABLE II. — *Examination of Blackstone River.* [Results expressed in Parts per 100,000.]

| Number.          | DATE.                  | LOCALITY.                                    | Ammonia. | "Abnormaloid."<br>Ammonia. | SOLID RESIDUE OF UNFILTERED WATER. |                             |        | SOLID RESIDUE OF UNFILTERED WATER. |                             |        | Chlorine. |
|------------------|------------------------|----------------------------------------------|----------|----------------------------|------------------------------------|-----------------------------|--------|------------------------------------|-----------------------------|--------|-----------|
|                  |                        |                                              |          |                            | Inor-<br>ganic.                    | Organic<br>and<br>Volatile. | Total. | Inor-<br>ganic.                    | Organic<br>and<br>Volatile. | Total. |           |
| • •              | October, 1872          | • • } Mill Brook, above sew-                 | 0.197    | 0.180                      | • •                                | • •                         | • •    | • •                                | • •                         | 15.91  | 1.62      |
| • •              | "                      | • • } ers, average of 12                     |          |                            |                                    |                             |        |                                    |                             |        |           |
| 99               | Friday, Nov. 8, '72    | • • } Mill Brook, below                      | 0.343    | 0.029                      | • •                                | • •                         | • •    | • •                                | • •                         | 14.90  | 2.74      |
| 100              | "                      | • • } sewers, aver. of 11                    |          |                            |                                    |                             |        |                                    |                             |        |           |
| 101              | "                      | • • } Mill Brook, before it                  | 0.158    | 0.120                      | • •                                | • •                         | • •    | • •                                | • •                         | 12.30  | 2.00      |
| 35 <sup>1</sup>  | Monday, June 30, '73   | • • } joins Kettle Brook                     |          |                            |                                    |                             |        |                                    |                             |        |           |
| 36 <sup>1</sup>  | "                      | • • } Kettle Brook                           | 0.012    | 0.025                      | • •                                | • •                         | • •    | • •                                | • •                         | 6.50   | • •       |
| 81               | Friday, July 18, '73   | • • } Blackstone River, near                 | 0.045    | 0.040                      | • •                                | • •                         | • •    | • •                                | • •                         | 8.00   | 0.80      |
| 82               | "                      | • • } Quinsig Iron Works                     | 0.180    | 0.0257                     | • •                                | • •                         | 10.6   | 3.40                               | 3.40                        | 6.80   | 0.86      |
|                  |                        |                                              | 0.110    | 0.0250                     | • •                                | • •                         | 11.2   | 4.10                               | 4.40                        | 8.50   | 0.80      |
| 133 <sup>2</sup> | Monday, Sept. 15, '73  | • • } Stone bridge over                      | 0.168    | 0.030                      | 11.50                              | 4.90                        | 16.40  | 7.60                               | 3.40                        | 11.00  | 1.14      |
| 134 <sup>3</sup> | "                      | • • } Blackstone, between                    | 0.170    | 0.031                      | 11.60                              | 4.90                        | 16.50  | 7.60                               | 3.40                        | 11.90  | 1.14      |
| 210 <sup>4</sup> | Thursday, Jan. 22, '74 | • • } Quinsigamond Vil-<br>lage and Millbury | 0.370    | 0.0410                     | • •                                | • •                         | • •    | 9.00                               | 2.70                        | 11.70  | 1.60      |
|                  |                        |                                              | 0.380    | 0.0400                     | • •                                | • •                         | • •    | 9.30                               | 4.70                        | 14.10  | 1.60      |
|                  |                        |                                              | 0.019    | 0.0127                     | 4.44                               | 0.76                        | 5.20   | 4.44                               | 0.60                        | 5.04   | 0.45      |

<sup>1</sup> Taken at different parts of the stream. <sup>2</sup> Oxygen 1.91 c.c. to the liter, the temperature being 19.75° C. <sup>3</sup> Oxygen 2.01 c.c. to the liter, the temperature being 19° C. <sup>4</sup> Oxygen 8.25 c.c. to the liter. This determination was made in the laboratory, the temperature being 18° C.

TABLE II. — *Examination of Blackstone River.* [Results expressed in Parts per 100,000.] — *Continued.*

| Number.          | DATE.                   | LOCALITY.                                            | Ammonia. | "Aluminoid."<br>Ammonia. | SOLID RESIDUE OF UNFILTERED WATER. |                       |        | SOLID RESIDUE OF FILTERED WATER. |                       |        | Chlorine. |
|------------------|-------------------------|------------------------------------------------------|----------|--------------------------|------------------------------------|-----------------------|--------|----------------------------------|-----------------------|--------|-----------|
|                  |                         |                                                      |          |                          | Inorganic.                         | Organic and Volatile. | Total. | Inorganic.                       | Organic and Volatile. | Total. |           |
|                  |                         |                                                      |          |                          |                                    |                       |        |                                  |                       |        |           |
| 37               | Monday, June 30, '73    | {<br>Wooden bridge above<br>the Burling Mills<br>}   | 0.150    | 0.0305                   | ..                                 | ..                    | 10.60  | 5.40                             | 5.00                  | 10.40  | 1.16      |
| 83               | Friday, July 18, '73    |                                                      | 0.045    | 0.0300                   | 6.00                               | 3.00                  | 9.00   | 4.50                             | 3.50                  | 8.00   | 0.54      |
| 135              | Monday, Sept. 15, '73   |                                                      | 0.025    | 0.0166                   | ..                                 | ..                    | ..     | ..                               | 3.00                  | 4.10   | 7.10      |
| 84               | Friday, July 18, '73    | {<br>Old canal, above the<br>Burling Mills<br>}      | 0.1000   | 0.0300                   | 5.40                               | 5.50                  | 10.90  | 4.50                             | 2.70                  | 7.20   | 0.60      |
| 136              | Monday, Sept. 15, '73   |                                                      | 0.0800   | 0.020                    | 3.70                               | 4.70                  | 8.40   | 4.00                             | 3.00                  | 7.00   | 0.84      |
| 102              | Friday, Nov. 8, '72     |                                                      | 0.0450   | 0.0400                   | ..                                 | ..                    | ..     | ..                               | ..                    | 5.00   | 1.20      |
| 38               | Monday, June 30, '73    | {<br>R. R. bridge, just<br>above Millbury<br>}       | 0.0400   | 0.0165                   | ..                                 | ..                    | ..     | 4.50                             | 2.50                  | 7.00   | 0.48      |
| 85 <sup>1</sup>  | Friday, July 18, '73    |                                                      | 0.0300   | 0.0165                   | 5.00                               | 4.00                  | 9.00   | 3.80                             | 4.20                  | 8.00   | 0.68      |
| 86 <sup>1</sup>  | "                       |                                                      | 0.0415   | 0.0200                   | 4.50                               | 4.20                  | 8.70   | 4.50                             | 3.00                  | 7.50   | 0.64      |
| 137 <sup>5</sup> | Monday, Sept. 15, '73   | {<br>Bel. Millbury Station,<br>at wooden bridge<br>} | 0.0250   | 0.0220                   | 3.20                               | 4.90                  | 8.10   | 3.30                             | 3.20                  | 6.50   | 0.68      |
| 211 <sup>6</sup> | Thursday, Jan. 22, '74  |                                                      | 0.0213   | 0.0120                   | 4.12                               | 0.76                  | 4.88   | 4.12                             | 0.68                  | 4.80   | 0.42      |
| 103              | Friday, Nov. 8, '72     |                                                      | 0.0370   | 0.0250                   | ..                                 | ..                    | ..     | ..                               | ..                    | 5.70   | 1.20      |
| 75               | Saturday, Sept. 28, '72 | {<br>Below Millbury Vil-<br>lage<br>}                | 0.0340   | 0.0250                   | ..                                 | ..                    | ..     | ..                               | ..                    | ..     | 0.65      |
| 39 <sup>1</sup>  | Monday, June 30, '73    |                                                      | 0.0320   | 0.0140                   | ..                                 | ..                    | 9.30   | 5.80                             | 1.00                  | 6.80   | 0.68      |
| 40 <sup>1</sup>  | "                       |                                                      | 0.0312   | 0.0140                   | ..                                 | ..                    | 9.00   | 6.00                             | 2.00                  | 8.00   | 0.64      |
| 138              | Monday, Sept. 15, '73   | {<br>Thursday, Jan. 22, '74<br>}                     | 0.0280   | 0.0200                   | 5.30                               | 2.00                  | 7.30   | 4.70                             | 2.10                  | 6.80   | 0.80      |
| 212 <sup>7</sup> | Thursday, Jan. 22, '74  |                                                      | 0.0283   | 0.0133                   | 4.52                               | 1.84                  | 6.36   | 4.28                             | 0.92                  | 5.20   | 0.44      |

|                 |                          |                                                                    |        |        |    |    |      |      |      |
|-----------------|--------------------------|--------------------------------------------------------------------|--------|--------|----|----|------|------|------|
| 72              | Saturday, Sept. 28, '72  | Saundersville, just before joining Quinsigamond river, Northbridge | 0.0192 | 0.0232 | .. | .. | ..   | 6.24 | 0.50 |
|                 | "                        |                                                                    | 0.0120 | 0.0224 | .. | .. | ..   | 6.68 | 0.30 |
| 68              | "                        |                                                                    |        |        |    |    |      |      |      |
| 51              | Thursday, July 3, '73    | Uxbridge, below Tat's Mill                                         | 0.0060 | 0.0224 | .. | .. | ..   | 5.68 | 0.22 |
| 143             | Wednesday, Sept. 17, '73 |                                                                    | 0.0068 | 0.1730 | .. | .. | 4.16 | 6.52 | 0.50 |
| 67              | Saturday, Sept. 28, '72  |                                                                    | 0.0053 | 0.0147 | .. | .. | 3.88 | 6.08 | 0.52 |
| 50              | Thursday, July 3, 1873   | Between Uxbridge and Millville                                     | 0.0080 | 0.1090 | .. | .. | ..   | 5.08 | 0.30 |
| 141             | Wednesday, Sept. 17, '73 |                                                                    | 0.0043 | 0.0132 | .. | .. | 2.96 | 4.82 | 0.32 |
| 49              | Thursday, July 3, '73    | Between Millville and Blackstone                                   | 0.0040 | 0.0147 | .. | .. | 2.88 | 4.60 | 0.40 |
| 140             | Wednesday, Sept. 17, '73 |                                                                    | 0.0066 | 0.0120 | .. | .. | 3.04 | 5.00 | 0.36 |
| 66              | Saturday, Sept. 28, '72  |                                                                    | 0.0073 | 0.0160 | .. | .. | 3.28 | 4.68 | 0.38 |
| 104             | Monday, Nov. 18, '72     |                                                                    | 0.0030 | 0.0190 | .. | .. | ..   | 4.80 | 0.23 |
| 47 <sup>s</sup> | Thursday, July 3, '73    | Below Blackstone                                                   | 0.0650 | 0.0350 | .. | .. | ..   | 6.50 | 0.60 |
| 48 <sup>s</sup> | "                        |                                                                    | 0.0064 | 0.0124 | .. | .. | 2.68 | 4.72 | 0.36 |
| 139             | Wednesday, Sept. 17, '73 |                                                                    | 0.0066 | 0.0131 | .. | .. | 2.84 | 4.92 | 0.36 |
|                 |                          | <i>Tributaries.</i>                                                | 0.0044 | 0.0164 | .. | .. | 2.76 | 5.08 | 0.40 |
| 73              | Saturday, Sept. 28, '72  | Quinsigamond River                                                 | 0.0040 | 0.0216 | .. | .. | ..   | 3.40 | 0.25 |
| 71              | "                        | Manchaug River, at Uxbridge Station                                | 0.0052 | 0.0212 | .. | .. | ..   | 4.20 | 0.28 |
| 142             | Wednesday, Sept. 17, '73 |                                                                    | 0.0043 | 0.0153 | .. | .. | 1.92 | 3.60 | 0.22 |
| 70              | Saturday, Sept. 28, '72  | West River, below Uxbridge                                         | 0.0040 | ..     | .. | .. | ..   | 3.84 | 0.20 |
| 144             | Wednesday, Sept. 17, '73 |                                                                    | 0.0044 | 0.0157 | .. | .. | 2.12 | 3.84 | 0.32 |

I Taken at different parts of the stream. 5 Oxygen 1.42 c.c. and 1.64 c.c. to the liter, the temperature being 19° C. The oxygen determination, 1.42, was made on the left-hand side of the stream; the 1.64 on the right-hand side; both in water taken a few inches below the surface. 6 Oxygen 7.38 c.c. Temperature at time of this determination was 18° C. 7 Oxygen 7.79 c.c. to the liter, the temperature at the time of examination being 18° C. 8 From different points.



TABLE II. a. — *Examination of Blackstone River.* [Results expressed in Grains per U. S. Gallon.]

| Number.          | DATE.                | LOCALITY.                                                                                           | Ammonia. | "Albuminoid,"<br>Ammonia. | SOLID RESIDUE OF UN-<br>FILTERED WATER. |                             | SOLID RESIDUE OF FIL-<br>TERED WATER. |                             | Chlorine. |
|------------------|----------------------|-----------------------------------------------------------------------------------------------------|----------|---------------------------|-----------------------------------------|-----------------------------|---------------------------------------|-----------------------------|-----------|
|                  |                      |                                                                                                     |          |                           | Inor-<br>ganic.                         | Organic<br>and<br>Volatile. | Inor-<br>ganic.                       | Organic<br>and<br>Volatile. |           |
| ..               | 1872 — October . . . | { Mill Brook, above sew-<br>ers, average of 12 . . }                                                | 0.115    | 0.105                     | ..                                      | ..                          | ..                                    | ..                          | 0.94      |
| ..               | " . . .              | { Mill Brook, below sew-<br>ers, average of 11 . . }                                                | 0.200    | 0.134                     | ..                                      | ..                          | ..                                    | ..                          | 1.60      |
| 99               | Nov. 8 . . .         | { Mill Brook, before it<br>joins Kettle Brook. }                                                    | 0.092    | 0.070                     | ..                                      | ..                          | ..                                    | ..                          | 1.17      |
| 100              | " . . .              | { Kettle Brook. . . . }                                                                             | 0.070    | 0.015                     | ..                                      | ..                          | ..                                    | ..                          | ..        |
| 101              | " . . .              | { . . . . . }                                                                                       | 0.026    | 0.023                     | ..                                      | ..                          | ..                                    | ..                          | 0.47      |
| 35 <sup>1</sup>  | 1873 — June 30 . . . | { Blackstone River, near<br>Quinsig. Iron Works }                                                   | 0.105    | 0.015                     | ..                                      | ..                          | 1.98                                  | 1.98                        | 0.50      |
| 36 <sup>1</sup>  | " . . .              | { . . . . . }                                                                                       | 0.064    | 0.015                     | ..                                      | ..                          | 2.39                                  | 2.57                        | 0.47      |
| 81 <sup>1</sup>  | July 18 . . .        | { Stone Bridge over Black-<br>stone River, between<br>Quinsigamond Village<br>and Milbury . . . . } | 0.098    | 0.018                     | 6.72                                    | 2.86                        | 4.44                                  | 1.98                        | 0.67      |
| 82 <sup>1</sup>  | " . . .              | { . . . . . }                                                                                       | 0.099    | 0.018                     | 6.77                                    | 2.86                        | 4.38                                  | 1.98                        | 0.67      |
| 132 <sup>2</sup> | Sept. 15 . . .       | { . . . . . }                                                                                       | 0.216    | 0.024                     | ..                                      | ..                          | 5.25                                  | 1.58                        | 0.93      |
| 134 <sup>3</sup> | " . . .              | { . . . . . }                                                                                       | 0.222    | 0.024                     | ..                                      | ..                          | 5.43                                  | 2.74                        | 0.93      |
| 210 <sup>4</sup> | 1874 — Jan. 22 . . . | { . . . . . }                                                                                       | 0.011    | 0.007                     | 2.59                                    | 0.44                        | 2.59                                  | 0.35                        | 0.27      |
| 37               | 1873 — June 30 . . . | { Wooden bridge above<br>the Burling Mills . . }                                                    | 0.088    | 0.018                     | ..                                      | ..                          | 3.15                                  | 2.92                        | 0.68      |
| 83               | July 18 . . .        | { . . . . . }                                                                                       | 0.026    | 0.018                     | ..                                      | ..                          | 2.63                                  | 2.04                        | 0.32      |
| 135              | Sept. 15 . . .       | { . . . . . }                                                                                       | 0.015    | 0.010                     | ..                                      | ..                          | 1.75                                  | 2.39                        | 0.42      |

|                  |               |                          |       |       |      |      |      |      |      |      |      |
|------------------|---------------|--------------------------|-------|-------|------|------|------|------|------|------|------|
| 84               | July 18       | Old Canal above the Bur- | 0.058 | 0.018 | 3.15 | 3.21 | 6.36 | 2.63 | 1.58 | 4.21 | 0.35 |
| 136              | Sept. 15      | ling Mills               | 0.047 | 0.012 | 2.16 | 2.74 | 4.90 | 2.33 | 1.75 | 4.08 | 0.49 |
| 102              | 1872—Nov. 8   | R. R. bridge just above  | 0.026 | 0.023 | ..   | ..   | ..   | ..   | ..   | 2.92 | 0.70 |
| 38               | 1873—June 30  |                          | 0.023 | 0.010 | ..   | ..   | ..   | 2.62 | 1.46 | 4.08 | 0.28 |
| 85 <sup>1</sup>  | July 18       |                          | 0.023 | 0.010 | 2.92 | 2.33 | 5.25 | 2.21 | 2.45 | 4.67 | 0.40 |
| 86 <sup>1</sup>  | "             | Millbury                 | 0.024 | 0.012 | 2.63 | 2.45 | 5.08 | 2.62 | 1.75 | 4.37 | 0.37 |
| 137 <sup>5</sup> | Sept. 15      |                          | 0.015 | 0.013 | 1.87 | 2.86 | 4.73 | 1.93 | 1.87 | 3.80 | 0.40 |
| 211 <sup>6</sup> | 1874—Jan. 22  |                          | 0.012 | 0.007 | 2.41 | 0.44 | 2.85 | 2.40 | 0.40 | 2.80 | 0.25 |
| 103              | 1872—Nov. 8   | Below Millbury Station   | 0.022 | 0.015 | ..   | ..   | ..   | ..   | ..   | 3.32 | 0.70 |
| 75               | Sept. 23      | Below Millbury           | 0.020 | 0.015 | 0.00 | ..   | ..   | ..   | ..   | ..   | 0.38 |
| 39 <sup>1</sup>  | 1873—June 30  |                          | 0.019 | 0.008 | ..   | ..   | 5.43 | 3.39 | 0.58 | 3.97 | 0.40 |
| 40 <sup>1</sup>  | "             |                          | 0.018 | 0.008 | ..   | ..   | 5.25 | 3.50 | 1.17 | 4.69 | 0.37 |
| 138              | Sept. 15      | Saundersville            | 0.012 | 0.012 | 3.09 | 1.17 | 4.26 | 2.74 | 1.23 | 3.97 | 0.47 |
| 212 <sup>7</sup> | 1874—Jan. 22  |                          | 0.012 | 0.008 | 2.64 | 1.07 | 3.71 | 2.50 | 0.54 | 3.04 | 0.26 |
| 74               | 1872—Sept. 28 |                          | 0.011 | 0.013 | ..   | ..   | ..   | ..   | ..   | 3.64 | 0.29 |
| 72               | "             | Northbridge              | 0.007 | 0.013 | ..   | ..   | ..   | ..   | ..   | 3.90 | 0.18 |
| 68               | "             | Uxbridge, below Taft's   | 0.004 | 0.013 | ..   | ..   | ..   | ..   | ..   | 3.32 | 0.13 |
| 51               | 1873—July 3   |                          | 0.004 | 0.010 | ..   | ..   | ..   | 2.43 | 1.38 | 3.81 | 0.29 |
| 143              | Sept. 17      | Mill                     | 0.003 | 0.009 | ..   | ..   | ..   | 2.26 | 1.28 | 3.54 | 0.30 |

1 Taken at different parts of the stream.

3 Oxygen 0.46 cubic inch to the gallon, the temperature being 66° F.

2 Oxygen 0.44 cubic inch to the gallon, temperature being 67.5° F.

4 Oxygen 1.91 cubic inch to the gallon.

5 Oxygen 0.33 and 0.38 cubic inch to the gallon, on different sides of the stream, the temperature being 66° F. 6 Oxygen 1.82 cubic inch to the gallon.

7 Oxygen 1.80 cubic inch to the gallon.

TABLE II. a. — *Examination of Blackstone River.* [Results expressed in Grains per U. S. Gallons.] — (Concluded.)

| Number.         | DATE.         | LOCALITY.                                         | Ammonia. | "Albuminoid"<br>Ammonia." | SOLID RESIDUE OF UN-<br>FILTERED WATER. |                             |        | SOLIE RESIDUE OF FIL-<br>TERED WATER. |                             |        | Chlorine. |
|-----------------|---------------|---------------------------------------------------|----------|---------------------------|-----------------------------------------|-----------------------------|--------|---------------------------------------|-----------------------------|--------|-----------|
|                 |               |                                                   |          |                           | Inorganic.                              | Organic<br>and<br>Volatile. | Total. | Inorganic.                            | Organic<br>and<br>Volatile. | Total. |           |
| 67              | 1872—Sept. 28 | { Between Uxbridge and<br>Millville . . . . . }   | 0.002    | 0.011                     | .                                       | .                           | .      | .                                     | .                           | 2.97   | 0.18      |
| 50              | 1873—July 3   |                                                   | 0.003    | 0.008                     | .                                       | .                           | .      | 1.73                                  | 1.09                        | 2.82   | 0.19      |
| 141             | Sept. 17      |                                                   | 0.002    | 0.009                     | .                                       | .                           | .      | 1.68                                  | 1.00                        | 2.68   | 0.23      |
| 49              | July 3        | { Between Millville and<br>Blackstone . . . . . } | 0.004    | 0.007                     | .                                       | .                           | .      | 1.77                                  | 1.14                        | 2.91   | 0.21      |
| 140             | Sept. 17      |                                                   | 0.004    | 0.009                     | .                                       | .                           | .      | 1.91                                  | 0.82                        | 2.73   | 0.22      |
| 66              | 1872—Sept. 28 |                                                   | 0.002    | 0.011                     | .                                       | .                           | .      | .                                     | .                           | 2.80   | 0.13      |
| 104             | Nov. 18       | { Below Blackstone . . }                          | 0.038    | 0.020                     | .                                       | .                           | .      | .                                     | .                           | 3.79   | 0.35      |
| 47 <sup>a</sup> | 1873—July 3   |                                                   | 0.004    | 0.007                     | .                                       | .                           | .      | 1.56                                  | 1.19                        | 2.75   | 0.21      |
| 18 <sup>a</sup> | "             |                                                   | 0.004    | 0.008                     | .                                       | .                           | .      | 1.65                                  | 1.21                        | 2.87   | 0.21      |
| 139             | Sept. 17      | <i>Tripartites.</i>                               | 0.003    | 0.010                     | .                                       | .                           | .      | 1.61                                  | 1.35                        | 2.96   | 0.23      |
| 73              | 1872—Sept. 28 | { Quinsigamond River . . }                        | 0.002    | 0.013                     | .                                       | .                           | .      | .                                     | .                           | 1.98   | 0.15      |
| 71              | "             |                                                   | 0.003    | 0.012                     | .                                       | .                           | .      | .                                     | .                           | 2.45   | 0.16      |
| 142             | 1873—Sept. 17 |                                                   | 0.003    | 0.009                     | .                                       | .                           | .      | 1.42                                  | 0.68                        | 2.10   | 0.13      |
| 70              | 1872—Sept. 28 | { West River, below Ux-<br>bridge . . . . . }     | 0.002    | .                         | .                                       | .                           | .      | .                                     | .                           | 2.24   | 0.12      |
| 144             | 1873—Sept. 17 |                                                   | 0.003    | 0.009                     | .                                       | .                           | .      | 1.24                                  | 1.00                        | 2.24   | 0.19      |

8 Taken at different points.

causes its waters to be ill-suited for any manufacturing operation is the suspended mineral matter with which it is, at some times, loaded; its use for domestic purposes will be discussed on subsequent pages.

#### BLACKSTONE RIVER.

An investigation into the condition of the Blackstone river, which was begun in 1872, has been continued during the present year. A description of the course of the river has been already given. (See the last Annual Report of the Board, page 82, and following.) The result of the examinations then made are incorporated with those made the present year in Tables Nos. II. and II.a. No further examination has been made of Mill brook; the considerable number of examinations made last year seemed to render it, at this time, unnecessary. It is sufficient to say that the condition of things with respect to it is essentially the same, although analysis might, and probably would show, the amount of impurity to be somewhat increased.

Specimens of the water have, however, been taken at various times at the stone bridge, just below Quinsigamond Village, about a mile below the junction of Mill brook and Kettle brook. Here the water, although varying somewhat in character, is always very foul. The water is always turbid, carrying a considerable amount of matter in suspension; the surface is covered with a greasy scum, and on one occasion a dead dog was seen stranded on a rock in the middle of the stream, and had already begun to decay.

A comparison of the results of the examination of the water taken from this and from other localities on the stream, as shown in Table II., is very interesting. That there should be so much difference in the character of the water at the same locality at different times, is not a matter to occasion surprise; it shows the value of a continued examination, and

the error involved in allowing a single examination to fix the character of a stream, especially of one which receives much sewage-matter. The samples are arranged in the table in the order of the localities from which they were taken proceeding from the upper part of the stream towards the mouth.

These examinations show a very different condition of things from that which exists in the case of the Merrimack. The Blackstone river receives, in the beginning, a very large amount of foul matter, — the sewage of Worcester. The various manufacturing establishments upon its banks contribute to its pollution. It is to be remarked, that the character of the bed is such, that the water as it flows seems, from its dark and turbid appearance, to be more foul than chemical examination shows it actually to be. Still, it is evident from an inspection of the table that the amount of pollution is considerable. From a comparison of the water just below Quinsigamond Village with that below Blackstone, it appears that, in respect to the total amount of impurity, to the chlorine, in every respect in fact, the condition of the water is better at the lower part of the stream. In the case of the Blackstone we can see, more readily than in that of the Merrimack, how largely this apparent decrease of impurity is owing to the entrance of streams less polluted, and to water draining from the surrounding country.\* We see, however, that the river at Blackstone still shows evidence of previous contamination. It may be remarked that, at the

\* I am informed by a gentleman largely interested in the mills on the Blackstone river and tributaries, that no measurements have, to his knowledge, been made of the flow of the river at any point within the State. He estimates however, the ordinary flow of the stream at the Rochdale Mills, at Northbridge, as being about 10,000 cubic feet per minute for twelve hours of each working-day. In Uxbridge, below the junction of the Blackstone and Manchaug rivers, it is about 18,000 cubic feet per minute for twelve hours of each working-day, and above the point at which the Little Blackstone enters the main stream in Grafton, there is probably not more than two-thirds as great a flow as at Northbridge.



time of the examination made September 15 and 17, the river was quite low, although not at the very lowest point reached during the summer. At the time of the examination made January 22, the river was quite full. The temperature of the air at this latter date was about 8° C. (46° F.), and there was little ice in the stream, although the water was near the freezing point.

#### CHARLES RIVER.

Charles river rises in the extreme south-western part of Norfolk County, and its water-shed includes a whole, or a part, of the towns of Bellingham (population in 1870, 1,283), Franklin (2,512), Medway (3,721), Norfolk (1,081), Medfield (1,142), Sherborn (1,062), Natick (6,404), Dover (645), Needham (3,607), Dedham (7,342), West Roxbury (8,683), Newton (12,825), Weston (1,261) and Waltham (9,065). The river empties into Boston Harbor, and, as a tidal stream, flows between Watertown, Cambridge and Charlestown on the one hand, and Brighton and Boston on the other. At the upper part of its course there are a few mills upon its banks, and from South Natick to the sea there is a succession of dams which, as the river has no very considerable fall, causes the water to set back for some distance. After the river becomes a tidal stream, it receives a large amount of sewage from the cities on its banks. The water of the stream above Newton is, as yet, but little contaminated. The amount of dissolved matter is small, as may be seen by an examination of the accompanying table. Having, in many places, a by no means rapid flow, and winding through low, marshy land, the amount of organic matter of vegetable origin is, especially in the latter part of the summer and during the fall, quite considerable; the water then becomes somewhat strongly colored, and possesses a slightly unpleasant taste. The town of Brookline, with a view to the possible

adoption of Charles river as a source of water-supply, had a number of chemical examinations made of the water at various times during the early part of the summer. The results of these examinations appear in the Brookline Water Report, September, 1873. For purposes of comparison, they are given in the Appendix to this report.

The amount of water flowing in Charles river above Newton has been measured at various times. Gaugings, made during July and August, 1841, showed a flow of about sixty-four cubic feet per second. During the month of September, 1845, which was a dry month, the average flow was about thirty cubic feet per second. This is, of course, less than the mean annual flow. The river has recently been estimated to be able, with sufficient storage capacity, to furnish a daily supply of 50,000,000 gallons; as, in this estimate, only two-thirds of total flow is taken into account, this would be equivalent to about 118 cubic feet per second as the mean flow. (See Report of Cochituate Water Board on an Additional Supply of water, 1873, p. 60.)

The "stations" chosen for the collection of water for chemical examination, were as follows:—

- A. *At South Natick*, at the dam.
- B. *At Charles-river Village*, above the dam.
- C. *At Dedham*, Ames-street bridge.
- C<sup>1</sup>. *At Dedham*, Spring-street bridge.

D. *At Needham*, Nahanton-street bridge, near the gravel pits. Between C and D the river makes a bend, so as to flow almost in a circle, and forms in one place what might be called a pond (known as Cow Bay). Above the Spring-street bridge is located an establishment for cleaning sheepskins, which, however, has seemed to be closed on every occasion on which the locality has been visited this summer. At this point (D) the river is very sluggish, it being, as a

rule, quite difficult to say, from simple observation of the stream, towards which direction the water flows.

E. *At Newton Upper Falls*, above the dam.

F. *Below Newton Lower Falls*, near the "Riverside" station, on the Boston and Albany Railroad.

G. *At Waltham*.

TABLE III. — *Examination of Charles River.* [Results expressed in Parts per 100,000.]

| Number.          | DATE.                      | LOCALITY.                                                  | Ammonia. | "Albuminoid"<br>Ammonia. | SOLID RESIDUE OF FILTERED<br>WATER. |                             |        | Chlorine. | Oxygen in cubic<br>centimeters to<br>the liter. |
|------------------|----------------------------|------------------------------------------------------------|----------|--------------------------|-------------------------------------|-----------------------------|--------|-----------|-------------------------------------------------|
|                  |                            |                                                            |          |                          | Inorganic.                          | Organic<br>and<br>Volatile. | Total. |           |                                                 |
| 31               | Saturday, June 28, 1873.   | { South Natick, . . . . . }                                | 0.0043   | 0.0120                   | 3.10                                | 1.80                        | 4.90   | 0.38.     | .                                               |
| 32               | " " " " " "                |                                                            | 0.0060   | 0.0100                   | 2.70                                | 1.30                        | 4.00   | 1.34      | .                                               |
| 15               | Thursday, " 12, " " " "    | { Charles River Village, above<br>dam, . . . . . }         | 0.0060   | 0.0209                   | 3.40                                | 1.80                        | 5.20   | 0.30      | .                                               |
| 33               | Saturday, " 28, " " " "    |                                                            | 0.0043   | 0.0127                   | 2.00                                | 2.00                        | 4.00   | 0.34      | .                                               |
| 34               | " " " " " "                | { Between Charles River Vil-<br>lage and Dedham, . . . . } | 0.0039   | 0.0146                   | 1.80                                | 3.20                        | 5.00   | 0.34      | .                                               |
| 16               | Thursday, " 12, " " " "    |                                                            | 0.0064   | 0.0189                   | 2.00                                | 2.50                        | 4.50   | 0.30      | .                                               |
| 182              | Saturday, Nov. 1, " " " "  | { Dedham, Ames St. Bridge, . . }                           | 0.0053   | 0.0280                   | 3.64                                | 3.00                        | 6.64   | 0.48      | .                                               |
| 28               | Thursday, June 26, " " " " |                                                            | 0.0100   | 0.0189                   | 3.00                                | 2.40                        | 5.40   | 0.32      | .                                               |
| 104              | Friday, Sept. 5, " " " "   | { Dedham, Spring St. Bridge. }                             | 0.0057   | 0.0327                   | 3.16                                | 3.80                        | 6.96   | 0.26      | .                                               |
| 183              | Saturday, Nov. 1, " " " "  |                                                            | 0.0056   | 0.0280                   | 3.72                                | 3.20                        | 6.92   | 0.48      | .                                               |
| 17               | Thursday, June 12, " " " " | { Bridge near Needham gravel-<br>pits, . . . . . }         | 0.0043   | 0.0165                   | 2.60                                | 2.7                         | 5.3    | 0.30      | .                                               |
| 29               | " " 26, " " " "            |                                                            | 0.0076   | 0.0151                   | 1.70                                | 3.1                         | 4.8    | 0.40      | .                                               |
| 18               | " " 12, " " " "            | { Bridge near Needham gravel-<br>pits, . . . . . }         | 0.0044   | 0.0179                   | 2.20                                | 2.70                        | 4.90   | 0.30      | .                                               |
| 30               | " " 26, " " " "            |                                                            | 0.0073   | 0.0173                   | 3.10                                | 3.70                        | 6.80   | 0.44      | .                                               |
| 105 <sup>1</sup> | Friday, Sept. 5, " " " "   | { Bridge near Needham gravel-<br>pits, . . . . . }         | 0.0066   | 0.0360                   | 2.84                                | 3.52                        | 6.36   | 0.24      | 2.89                                            |
| 184              | Saturday, Nov., 1 " " " "  |                                                            | 0.0044   | 0.0250                   | 3.96                                | 2.48                        | 6.44   | 0.48      | .                                               |

|                  |                   |   |    |   |       |                                                        |        |        |      |      |      |      |      |
|------------------|-------------------|---|----|---|-------|--------------------------------------------------------|--------|--------|------|------|------|------|------|
| 106 <sup>1</sup> | Friday, Sept. 5,  | " | 5, | " | ..... | } Newton Upper Falls, above<br>dam, .....              | 0.0057 | 0.0368 | 3.40 | 3.92 | 7.32 | 0.26 | 2.95 |
| 107 <sup>1</sup> | "                 | " | "  | " | ..... |                                                        | 0.0060 | 0.0340 | 3.04 | 3.76 | 6.80 | 0.32 | 2.73 |
| 97               | Monday,           | " | 1, | " | ..... | } Below Newton Lower Falls<br>and above Waltham, . . . | 0.0077 | 0.0307 | 3.20 | 3.16 | 6.36 | 0.26 | 3.23 |
| 98               | "                 | " | "  | " | ..... |                                                        | 0.0060 | 0.0307 | 3.16 | 3.24 | 6.40 | 0.26 | 2.93 |
| 99               | "                 | " | "  | " | ..... |                                                        | 0.0053 | 5.0407 | 3.40 | 3.24 | 6.64 | 0.30 | ..   |
| 100              | "                 | " | "  | " | ..... |                                                        | 0.0064 | 0.0444 | 3.00 | 3.28 | 6.28 | 0.30 | 2.74 |
| 107              | Tuesday, Dec. 16, | " | "  | " | ..... | Waltham,                                               | 0.0060 | 0.0164 | 3.88 | 1.84 | 5.72 | 0.40 | ..   |

1 Nos. 105, 106 and 107 were found *after they had been carried to the laboratory* to contain dissolved gases as follows:—

No. 105, Nitrogen 9.10, Oxygen 2.84 c. c. per liter.  
 106, " " 8.08, " 2.95 "  
 107, " " 7.68, " 2.73 "



TABLE III. a. — *Examination of Charles River.* [Results expressed in Grains per U. S. Gallon.]

| Number. | DATE.          | LOCALITY.                                                  | Ammonia. | "Albuminoid"<br>Ammonia. | SOLID RESIDUE OF FILTERED<br>WATER. |                             |        | Chlorine. | Oxygen in cubic<br>Inches to the<br>gallon. |
|---------|----------------|------------------------------------------------------------|----------|--------------------------|-------------------------------------|-----------------------------|--------|-----------|---------------------------------------------|
|         |                |                                                            |          |                          | Inorg'nic.                          | Organic<br>and<br>Volatile. | Total. |           |                                             |
| 31      | June 28, 1873. | { South Natick, . . . . . }                                | 0.0025   | 0.0069                   | 1.81                                | 1.05                        | 2.86   | 0.22      | . .                                         |
| 32      | " "            |                                                            | 0.0035   | 0.0058                   | 1.58                                | 0.75                        | 2.33   | 0.20      | . .                                         |
| 15      | " 12, "        | { Charles River Village, above<br>dam, . . . . . }         | 0.0035   | 0.0122                   | 1.98                                | 1.05                        | 3.03   | 0.18      | . .                                         |
| 33      | " 28, "        |                                                            | 0.0025   | 0.0074                   | 1.17                                | 1.17                        | 2.34   | 0.20      | . .                                         |
| 34      | " "            |                                                            | 0.0023   | 0.0085                   | 1.05                                | 1.87                        | 2.92   | 0.20      | . .                                         |
| 16      | " 12, "        | { Between Charles River Vil-<br>lage and Dedham, . . . . } | 0.0037   | 0.0110                   | 1.17                                | 1.46                        | 2.63   | 0.18      | . .                                         |
| 182     | Nov. 1, "      |                                                            | 0.0031   | 0.0163                   | 2.12                                | 1.75                        | 3.87   | 0.23      | . .                                         |
| 28      | June 26, "     | { Dedham, Ames St. Bridge, . }                             | 0.0058   | 0.0110                   | 1.75                                | 1.40                        | 3.15   | 0.19      | . .                                         |
| 104     | Sept. 5, "     |                                                            | 0.0033   | 0.0191                   | 1.84                                | 2.22                        | 4.06   | 0.15      | . .                                         |
| 183     | Nov. 1, "      | { Dedham, Spring St. Bridge, . }                           | 0.0033   | 0.0163                   | 2.17                                | 1.87                        | 4.04   | 0.23      | . .                                         |
| 17      | June 12, "     |                                                            | 0.0025   | 0.0096                   | 1.51                                | 1.57                        | 3.09   | 0.18      | . .                                         |
| 29      | " 26, "        | { Bridge, n'r Needham gravel-<br>pit, . . . . . }          | 0.0044   | 0.0076                   | 0.99                                | 1.81                        | 2.80   | 0.23      | . .                                         |
| 18      | " 12, "        |                                                            | 0.0026   | 0.0104                   | 1.28                                | 1.57                        | 2.85   | 0.18      | . .                                         |
| 30      | " 26, "        |                                                            | 0.0043   | 0.0101                   | 1.81                                | 2.16                        | 3.97   | 0.26      | . .                                         |
| 105     | Sept. 5, "     | { . . . . . }                                              | 0.0039   | 0.0210                   | 1.66                                | 2.06                        | 3.72   | 0.14      | 0.69                                        |
| 185     | Nov. 1, "      |                                                            | 0.0026   | 0.0146                   | 2.31                                | 1.45                        | 3.76   | 0.23      | . .                                         |

|     |            |           |                                                        |        |        |      |      |      |      |       |
|-----|------------|-----------|--------------------------------------------------------|--------|--------|------|------|------|------|-------|
| 106 | Sept. 5, " | . . . . . | } Newton Upper Falls, above {<br>dam, . . . . .        | 0.0033 | 0.0215 | 1.98 | 2.29 | 4.27 | 0.15 | 0.68  |
| 107 | "          | . . . . . |                                                        | 0.0035 | 0.0198 | 1.77 | 2.20 | 3.97 | 0.19 | 0.63  |
| 97  | "          | . . . . . |                                                        | 0.0045 | 0.0179 | 1.87 | 1.84 | 3.71 | 0.15 | 0.75  |
| 98  | "          | . . . . . | } Between Newton Lower Falls<br>and Waltham, . . . . . | 0.0035 | 0.0179 | 1.84 | 1.89 | 3.73 | 0.15 | 0.69  |
| 99  | "          | . . . . . |                                                        | 0.0031 | 0.0237 | 1.98 | 1.89 | 3.87 | 0.18 | . . . |
| 100 | "          | . . . . . |                                                        | 0.0039 | 0.0257 | 1.75 | 1.91 | 3.66 | 0.18 | 0.63  |
| 197 | Dec. 16, " | . . . . . | Waltham, . . . . .                                     | 0.0035 | 0.0096 | 2.27 | 1.07 | 3.34 | 0.23 | . . . |

In addition to the results recorded in Tables III. and III. *a*, more complete analyses were also made of the water taken at Needham bridge, November 1 (No. 184), and of water taken at Waltham, December 16 (No. 197). The results obtained were as follows : —

|                                     | PARTS PER 100,000. |          | GRAINS PER GALLON. |          |
|-------------------------------------|--------------------|----------|--------------------|----------|
|                                     | No. 184.           | No. 197. | No. 184.           | No. 197. |
| Ammonia . . . . .                   | 0.0044             | 0.0060   | 0.0026             | 0.0035   |
| "Albuminoid Ammonia" . . . . .      | 0.0250             | 0.0164   | 0.0144             | 0.0096   |
| Inorganic . . . . .                 | 3.96               | 3.88     | 2.31               | 2.26     |
| Organic and Volatile . . . . .      | 2.48               | 1.84     | 1.45               | 1.07     |
| Total solid residue . . . . .       | 6.44               | 5.72     | 3.76               | 3.33     |
| Chlorine . . . . .                  | 0.48               | 0.40     | 0.28               | 0.23     |
| Sulphuric acid (SOs) . . . . .      | 0.54               | 0.89     | 0.32               | 0.52     |
| Silica . . . . .                    | 0.65               | 0.67     | 0.38               | 0.33     |
| Alumina and oxide of iron . . . . . | 0.43               | 0.19     | 0.25               | 0.11     |
| Lime . . . . .                      | 0.53               | 0.71     | 0.31               | 0.41     |
| Magnesia . . . . .                  | trace.             | 0.02     | trace.             | trace.   |

#### SUDBURY AND CONCORD RIVERS.

Similar to the Charles-river water is that of the Sudbury river, or, as it is called after the junction with the Assabet, the Concord river.

The Sudbury rises in and flows through meadow lands, acquiring thereby in the late summer and fall a yellow, almost brown color. This color, the present year at least, has been more pronounced than in the case of Charles river, and on account of the thus far open winter the color has persisted longer than it sometimes does. The amount of organic matter, however, at the present writing (December 20) is much less than it was in September and October. As the Sudbury will

be considered more fully with reference to its proposed use as a supply for Boston and suburbs, attention is simply called at this point to the results of chemical examination given in Tables IV. and IV. *a*.

Below the point at which it is proposed to divert a portion of the water of the Sudbury for metropolitan use, the river passes through Saxonville, where there are woollen mills, and in the town of Concord joins the Assabet. The Assabet is formed by the junction of various brooks which rise in Northborough and in adjoining towns; it flows through Hudson and Stow, and then into Concord.

The united stream bears the name of Concord, and flows between Bedford and Carlisle, then through Billerica and Lowell, in which latter town it joins the Merrimack. At Billerica there are somewhat extensive woollen mills, and at Lowell the water of the river is used to furnish power to several manufactories.

The "stations" chosen for the collection of water for chemical examination were as follows:—

A. *Above Ashland.*

B. *Below Ashland*, after the river has been joined by Col Spring brook, coming from Hopkinton.

C. *In Framingham*, just above the point where the water of the river has been diverted into Farm pond.

D. *In Concord*, before the Assabet joins the Sudbury.

E. *In Concord*, below the junction of the Sudbury and Assabet.

F. *Billerica*, above the mills.

G. *Above Lowell*, at seven-arch bridge.

H. *In Lowell.*

TABLE IV. — *Examination of Sudbury and Concord Rivers.* [Results expressed in Parts per 100,000.]

| Number.          | DATE.                       | LOCALITY.                                | Ammonia. | "Albuminoid."<br>Ammonia. | SOLID RESIDUE OF FILTERED<br>WATER. |                             |        | Chlorine. |
|------------------|-----------------------------|------------------------------------------|----------|---------------------------|-------------------------------------|-----------------------------|--------|-----------|
|                  |                             |                                          |          |                           | Inor-<br>ganic.                     | Organic<br>and<br>Volatile. | Total. |           |
| 181              | 1873 — October 23 . . . . . | { Cold Spring Brook, Ashland . . . . . } | 0.0037   | 0.0177                    | 2.92                                | 3.12                        | 6.04   | 0.35      |
| 199 <sup>1</sup> | December 17 . . . . .       |                                          | 0.0044   | 0.0131                    | 2.88                                | 1.52                        | 4.40   | 0.24      |
| 156              | September 22 . . . . .      | { Sudbury River, above Ashland . . . }   | 0.0057   | 0.0313                    | 2.96                                | 3.04                        | 6.00   | 0.23      |
| 180              | October 23 . . . . .        |                                          | 0.0051   | 0.0184                    | 2.80                                | 4.28                        | 7.08   | 0.40      |
| 198 <sup>2</sup> | December 17 . . . . .       | { Below Ashland . . . . . }              | 0.0044   | 0.0141                    | 3.40                                | 1.32                        | 4.72   | 0.24      |
| 155              | September 22 . . . . .      |                                          | 0.0067   | 0.0257                    | 3.08                                | 3.44                        | 6.52   | 0.20      |
| 179              | October 23 . . . . .        | { Sudbury River, at Framingham . . . }   | 0.0053   | 0.0254                    | 2.56                                | 3.76                        | 6.32   | 0.26      |
| 200 <sup>3</sup> | December 17 . . . . .       |                                          | 0.0044   | 0.0113                    | 2.88                                | 1.60                        | 4.48   | 0.24      |
| 154              | September 22 . . . . .      | { Sudbury River, at Framingham . . . }   | 0.0060   | 0.0300                    | 3.60                                | 3.03                        | 6.63   | 0.23      |
| 46               | July 1 . . . . .            |                                          | 0.0060   | 0.0140                    | 3.60                                | 1.90                        | 5.50   | 0.32      |
| 153              | September 23 . . . . .      | { Sudbury River, at Framingham . . . }   | 0.0047   | 0.0231                    | 2.44                                | 2.68                        | 5.12   | 0.23      |
| 178              | October 23 . . . . .        |                                          | 0.0064   | 0.0247                    | 2.80                                | 4.40                        | 7.20   | 0.44      |
| 207 <sup>4</sup> | December 17 . . . . .       | { Sudbury River at Concord . . . . . }   | 0.0048   | 0.0127                    | 3.08                                | 1.92                        | 5.00   | 0.24      |
| 49 <sup>5</sup>  | February 19 . . . . .       |                                          | 0.0060   | 0.0207                    | 2.48                                | 1.80                        | 4.28   | 0.23      |
| 59               | July 9 . . . . .            | { Sudbury River at Concord . . . . . }   | 0.0047   | 0.0173                    | 4.00                                | 2.20                        | 6.20   | 0.30      |
| 60               | " . . . . .                 |                                          | 0.0044   | 0.0197                    | 3.80                                | 2.24                        | 6.04   | 0.30      |
| 162              | September 23 . . . . .      | { Sudbury River at Concord . . . . . }   | 0.0067   | 0.0247                    | 3.00                                | 2.92                        | 5.92   | 0.32      |
|                  |                             |                                          |          |                           |                                     |                             |        |           |



|                  |                            |                                          |        |        |      |      |      |      |
|------------------|----------------------------|------------------------------------------|--------|--------|------|------|------|------|
| 61               | 1873—July 9 . . . . .      |                                          | 0.0044 | 0.0204 | 2.96 | 2.00 | 4.96 | 0.32 |
| 62               | “ . . . . .                | Assabet, at Concord . . . . .            | 0.0051 | 0.0217 | 2.92 | 2.12 | 5.04 | 0.32 |
| 161              | September 23 . . . . .     |                                          | 0.0053 | 0.0227 | 2.84 | 2.28 | 5.12 | 0.30 |
| 63               | July 9 . . . . .           |                                          | 0.0040 | 0.0188 | 2.64 | 2.40 | 5.04 | 0.26 |
| 64               | “ . . . . .                |                                          | 0.0040 | 0.0193 | 3.08 | 2.24 | 5.32 | 0.28 |
| 150              | September 23 . . . . .     | Concord River, at Concord . . . . .      | 0.0080 | 0.0271 | 3.08 | 2.44 | 5.52 | 0.34 |
| 160              | “ . . . . .                |                                          | 0.0067 | 0.0264 | 3.20 | 2.80 | 6.00 | 0.34 |
| 53               | July 8 . . . . .           | Concord, above North Billerica . . . . . | 0.0057 | 0.0173 | 3.00 | 1.60 | 4.60 | 0.36 |
| 54               | “ . . . . .                | Concord, at North Billerica, just above  | 0.0040 | 0.0207 | 2.84 | 2.56 | 5.40 | 0.34 |
| 55               | “ . . . . .                | the mills . . . . .                      | 0.0060 | 0.0187 | 2.60 | 2.20 | 4.80 | “    |
| 118              | 1872—November 30 . . . . . |                                          | 0.0200 | 0.0500 | “    | “    | 2.60 | 0.30 |
| 56               | 1873—July 8 . . . . .      |                                          | 0.0053 | 0.0188 | 3.42 | 2.08 | 5.50 | 0.32 |
| 57               | “ . . . . .                |                                          | 0.0065 | 0.0220 | 3.06 | 2.04 | 5.10 | 0.34 |
| 58               | “ . . . . .                | Lowell, 7-arch Bridge . . . . .          | 0.0066 | 0.0230 | 3.06 | 1.80 | 4.86 | 0.34 |
| 112              | September 8 . . . . .      |                                          | 0.0081 | 0.0300 | 3.68 | 2.92 | 6.60 | 0.24 |
| 113              | “ . . . . .                |                                          | 0.0081 | 0.0324 | 3.20 | 2.84 | 6.04 | 0.26 |
| 191              | November 13 . . . . .      |                                          | 0.0056 | 0.0253 | 3.96 | 2.28 | 6.24 | 0.38 |
| 72 <sup>10</sup> | July 10 . . . . .          | Lowell, Church-street Bridge . . . . .   | 0.0047 | 0.0207 | 5.45 | 2.70 | 8.15 | 0.40 |
| 73 <sup>10</sup> | “ . . . . .                |                                          | 0.0047 | 0.0167 | 4.88 | 2.72 | 7.60 | 0.44 |
| 119              | 1872—November 30 . . . . . | Merrimack-street Bridge . . . . .        | 0.0230 | 0.0430 | “    | “    | 5.10 | 0.34 |

1 Oxygen 7.0 c.c. to the liter. 2 Oxygen 7.2 c.c. to the liter. 3 Oxygen 6.6 c.c. to the liter. 4 Oxygen 7.9 c.c. to the liter. The determinations of oxygen in Nos. 191, 198, 200, 201 were made December 18, in the laboratory. 5 Examination of water made by W. R. N. for the town of Brookline, February, 1873, and printed in the report of Messrs. Seald and Sawyer, Civil Engineers, to the town meeting. 6 Right-hand arch, a little out of current. 7 Next arch, in the current. 8 Third arch, in the current. 9 Taken at different parts of the stream. Oxygen 1.02 c.c. per liter. 10 Taken at different parts of the stream.

TABLE IV. a. — *Examination of Sudbury and Concord Rivers.* [Results expressed in Grains per U. S. Gallon.]

| Number.          | DATE.                       | LOCALITY.                              | Ammonia. | "Albuminoid"<br>Ammonia." | SOLID RESIDUE OF FILTERED<br>WATER. |                             |        | Chlorine. |
|------------------|-----------------------------|----------------------------------------|----------|---------------------------|-------------------------------------|-----------------------------|--------|-----------|
|                  |                             |                                        |          |                           | Inorganic.                          | Organic<br>and<br>Volatile. | Total. |           |
| 181              | 1873 — October 23 . . . . . | { Cold-Spring Brook, Ashland . . . }   | 0.0022   | 0.0103                    | 1.70                                | 1.82                        | 3.52   | 0.21      |
| 190 <sup>1</sup> | December 17 . . . . .       |                                        | 0.0026   | 0.0076                    | 1.68                                | 0.89                        | 2.57   | 0.14      |
| 156              | September 22 . . . . .      |                                        | 0.0039   | 0.0183                    | 1.73                                | 1.77                        | 3.50   | 0.16      |
| 180              | October 23 . . . . .        | { Sudbury River, above Ashland . . }   | 0.0030   | 0.0107                    | 1.63                                | 2.30                        | 4.13   | 0.23      |
| 198 <sup>2</sup> | December 17 . . . . .       |                                        | 0.0026   | 0.0082                    | 1.98                                | 0.77                        | 2.75   | 0.14      |
| 155              | September 22 . . . . .      |                                        | 0.0039   | 0.0168                    | 1.80                                | 2.01                        | 3.81   | 0.17      |
| 179              | October 23 . . . . .        | { Below Ashland . . . . . }            | 0.0031   | 0.0148                    | 1.49                                | 2.20                        | 3.69   | 0.21      |
| 200 <sup>3</sup> | December 17 . . . . .       |                                        | 0.0026   | 0.0066                    | 1.68                                | 0.93                        | 2.61   | 0.14      |
| 154              | September 22 . . . . .      |                                        | 0.0035   | 0.0175                    | 2.10                                | 1.90                        | 4.00   | 0.16      |
| 46               | July 1 . . . . .            | { Below Ashland, further down stream } | 0.0035   | 0.0080                    | 2.10                                | 1.11                        | 3.21   | 0.19      |
| 153              | September 23 . . . . .      |                                        | 0.0027   | 0.0152                    | 1.42                                | 1.57                        | 2.99   | 0.16      |
| 178              | October " . . . . .         |                                        | 0.0037   | 0.0144                    | 1.63                                | 2.57                        | 4.20   | 0.23      |
| 201 <sup>4</sup> | December 17 . . . . .       | { Sudbury River at Framingham . . }    | 0.0028   | 0.0074                    | 1.80                                | 1.12                        | 2.92   | 0.14      |
| 49               | February 19 . . . . .       |                                        | 0.0035   | 0.0121                    | 1.45                                | 1.05                        | 2.50   | ...       |
| 59               | July 9 . . . . .            |                                        | 0.0027   | 0.0101                    | 2.84                                | 1.28                        | 3.62   | 0.16      |
| 60               | " . . . . .                 | { Sudbury, at Concord . . . . . }      | 0.0026   | 0.0115                    | 2.22                                | 1.51                        | 3.53   | 0.18      |
| 162              | September 23 . . . . .      |                                        | 0.0039   | 0.0144                    | 1.75                                | 1.70                        | 3.45   | 0.19      |

|     |                            |                                                                    |        |        |       |       |      |       |
|-----|----------------------------|--------------------------------------------------------------------|--------|--------|-------|-------|------|-------|
| 61  | 1873—July 9 . . . . .      | { Assabet, at Concord . . . . . }                                  | 0.0020 | 0.0119 | 1.73  | 1.17  | 2.90 | 0.19  |
| 62  | " . . . . .                |                                                                    | 0.0030 | 0.0127 | 1.70  | 1.24  | 2.94 | 0.19  |
| 161 | September 23 . . . . .     |                                                                    | 0.0031 | 0.0132 | 1.66  | 1.33  | 2.00 | 0.18  |
| 63  | July 9 . . . . .           | { Concord River, at Concord . . . . . }                            | 0.0023 | 0.0110 | 1.54  | 1.40  | 2.94 | 0.15  |
| 64  | " . . . . .                |                                                                    | 0.0023 | 0.0113 | 1.80  | 1.31  | 3.11 | 0.16  |
| 159 | September 23 . . . . .     |                                                                    | 0.0047 | 0.0158 | 1.80  | 1.42  | 3.22 | 0.20  |
| 160 | " . . . . .                | { Concord, above North Billerica . . . }                           | 0.0039 | 0.0154 | 1.87  | 1.63  | 3.50 | 0.20  |
| 53  | July 8 . . . . .           |                                                                    | 0.0033 | 0.0101 | 1.75  | 0.93  | 2.68 | 0.21  |
| 54  | " . . . . .                |                                                                    | 0.0023 | 0.0121 | 1.66  | 1.49  | 3.15 | 0.20  |
| 55  | " . . . . .                | { Concord, at North Billerica, just above<br>the mills . . . . . } | 0.0035 | 0.0109 | 1.52  | 1.28  | 2.80 | . . . |
| 118 | 1872—November 30 . . . . . | { Concord River, at 7-arch Bridge,<br>Lowell . . . . . }           | 0.0117 | 0.0233 | . . . | . . . | 1.52 | 0.18  |
| 56  | 1873—July 8 . . . . .      |                                                                    | 0.0037 | 0.0110 | 2.00  | 1.21  | 3.21 | 0.19  |
| 57  | " . . . . .                |                                                                    | 0.0038 | 0.0123 | 1.79  | 1.19  | 2.98 | 0.20  |
| 58  | " . . . . .                | { Lowell . . . . . }                                               | 0.0039 | 0.0134 | 1.79  | 1.05  | 2.84 | 0.20  |
| 112 | September " . . . . .      |                                                                    | 0.0047 | 0.0175 | 2.15  | 1.70  | 3.85 | 0.14  |
| 113 | " . . . . .                |                                                                    | 0.0047 | 0.0189 | 1.87  | 1.66  | 3.53 | 0.15  |
| 191 | November 13 . . . . .      | { Church street Bridge, Lowell . . . . . }                         | 0.0033 | 0.0148 | 2.31  | 1.33  | 3.64 | 0.22  |
| 72  | " 10 . . . . .             |                                                                    | 0.0027 | 0.0121 | 3.18  | 1.58  | 4.76 | 0.23  |
| 73  | " . . . . .                |                                                                    | 0.0027 | 0.0097 | 2.85  | 1.59  | 4.44 | 0.25  |
| 119 | 1872—November 30 . . . . . | Merrimack street Bridge, Lowell . .                                | 0.0134 | 0.0250 | . . . | . . . | 2.98 | 0.20  |

3 Oxygen 1.52 cubic inch to the gallon.

2 Oxygen 1.66 cubic inch to the gallon.

1 Oxygen 1.62 cubic inch to the gallon.

4 Oxygen 1.82 cubic inch to the gallon. The determinations of oxygen in Nos. 199, 200, 201, were made on December 18, in the laboratory.

The flow of the Sudbury river at Framingham has been estimated, from its drainage area, to be about 40,000,000 gallons daily, or about 63 cubic feet per second. As to the flow of the Concord, something has already been said on page 80.

From the results of the chemical examinations of the rivers which have been under consideration the present year, it appears that no one of them, with the exception of the Blackstone, can be called foul. This river is foul in the upper part of its course, although, for the present, the dilution of the polluted stream with water less polluted than its own, preserves the lower portion of the stream in a tolerably good condition.

The Charles, Sudbury, Assabet, and Concord rivers are very different in character from the Merrimack or the Blackstone. Formed as they are by brooks which rise in meadowland, and flowing as they do through meadows and marshes, the waters are characterized, especially in the late summer and fall, by the presence, in solution, of a considerable amount of vegetable matter, which gives the water a yellow or brown color, already alluded to. These rivers are usually very clear, and although rendered somewhat turbid by heavy rains do not show such marked changes, with respect to the suspended matter, as are exhibited by the Merrimack. As yet these streams are not made, to any extent, the carriers of sewage in the upper part of their flow; allusion has already been made to their receiving sewage and manufacturing refuse near their mouths.

#### NEPONSET RIVER.

The Neponset river is similar in character to the streams last considered. It receives some manufacturing refuse, and, at the lower part of its course, it is made the receptacle of sewage. A single examination of the water has been made at Readville, and one below Hyde Park. The result of the chemical examination was as follows:—

|                                | PARTS PER 100,000. |                     | GRAINS PER GALLON. |                     |
|--------------------------------|--------------------|---------------------|--------------------|---------------------|
|                                | At<br>Readville.   | Below<br>Hyde Park. | At<br>Readville.   | Below<br>Hyde Park. |
| Ammonia . . . . .              | 0.0047             | 0.0110              | 0.0027             | 0.0064              |
| "Albuminoid Ammonia" . . . . . | 0.0270             | 0.0300              | 0.0158             | 0.0175              |
| Mineral . . . . .              | 2.40               | 3.60                | 1.40               | 2.10                |
| Organic and volatile . . . . . | 3.40               | 8.04                | 1.98               | 1.77                |
| Total solid residue . . . . .  | 5.80               | 6.64                | 3.38               | 3.87                |
| Chlorine . . . . .             | 0.50               | 0.52                | 0.29               | 0.30                |

## ON RIVERS AS A SOURCE OF WATER-SUPPLY.

In the preceding pages an account has been given of the results obtained from the examination of water from certain of our running streams. We are naturally led to consider the bearing of the facts observed on the question of the use of rivers as a source of supply of water for domestic purposes. The matter was, to some extent, discussed in the report made to the Board last year, and I desire to repeat and emphasize the statements made at that time. The order of the Legislature, in accordance with which this investigation was begun, alluded to the "joint use of water-courses for sewers and as sources of supply for domestic use." I believe that all such joint use is to be deprecated, and because of the very great difficulty, I might say impossibility, of preventing the use of running-streams as sewers to a certain extent, their use as sources of domestic supply, at least at such portion of their course as lies below thickly settled and manufacturing towns, is not to be advised. For this reason, in a previous report, the great ponds of the Commonwealth have been looked to as affording a better source of supply. It is, however, to be borne in mind that the objection is not to the river as such. A river may, considered by itself, afford a most excellent, a



perfectly unobjectionable, supply of water. Its sources may be clear and pure mountain-streams ; it may flow over a rocky or gravelly bed, uncontaminated by refuse from the habitations and factories of men, and free, or nearly so, from vegetable matter ; it may be so situated that no liquid refuse finds its way to it, without being first purified by filtration through a sufficient amount of natural soil. In this case no objection can be made to using the water for all domestic purposes. On the other hand, a pond or lake may be, in itself, a very objectionable source of supply, especially if so situated as to receive direct drainage, or if fed by streams which are used as sewers. It is an indispensable condition in the choice of any stream or lake as a source of water-supply, that the source should not only be free from actual present contamination, but should also be so situated as to render it possible to protect it from contamination in the future. A striking instance of the danger to which a lake used as a source of water-supply may be exposed, is afforded by Mystic lake, which will presently be alluded to more fully.

It is very far from being my desire to awaken unnecessary anxiety in any mind with reference to the desired purity of our sources of water-supply. It is very true that a large amount of refuse material is of such a character as to be, except in excessive quantities, of no appreciable influence on the human system ; the addition of the inorganic compounds of lime, soda, potash, etc., would have no deleterious effect ; in fact, although the lime-compounds increase the hardness of water and make it less desirable for washing, the presence of a moderate amount of mineral substances makes the water more palatable, and, very probably also, more wholesome.\*

\*It is well known that freshly-distilled water is very insipid. This is in part owing to its freedom from dissolved gases, but partly also to the absence of mineral salts. On shipboard the water is aerated before being used to drink, and it has been proposed to render it more palatable and more wholesome by the addition of a certain amount of mineral salts. A mixture which

Then in the case of many waste liquors which appear to be very offensive, the matter which really could be regarded as injurious is comparatively small in amount. If we consider the character of the substances discharged by different manufacturing establishments, we shall find them very different; some of them are such as to be universally regarded as unfit to admit to any stream, — those, for instance, containing lead, arsenic, etc.; others, such as salts of iron, are scarcely regarded as injurious; thus, the discharge of sulphate of iron (copperas) into a stream already polluted with sewage-matter might, within certain limits, be of positive advantage (see last Report of the Board of Health, pages 97, 98). Again, in the case of some of the vegetable dyestuffs, the weak, spent dye-liquors, although they communicate a very foul appearance to the water for some distance, yet contain a comparatively small amount of solid matter, and if discharged into a stream of considerable size, are soon disseminated through it, and diluted to a very great extent.

Much depends, of course, upon the size of the stream into which the refuse is thrown. Thus, while into the Merrimack at Lowell, even during the summer, it would be necessary to throw more than 100 tons of solid matter daily in order to increase the amount in the water by one grain to the gallon, another and smaller stream might be hopelessly fouled by a single factory.

Different in character, however, from much of the refuse of manufacturing establishments is the sewage coming from our dwellings, or the sewage (in its more restricted sense, of excremental matter from animal sources) which comes

has been proposed for this purpose consists, for 1,000 liters of water, of 4.8 grams salt, 3.4 grams sulphate of soda, 48 grams bicarbonate of lime [? w. r. n.] 14 grams carbonate of soda, and 6 grams carbonate magnesia. It is stated that the Russian navy has adopted this idea, and furnished to its vessels a mixture of this character. — *Fonssagrives. Hygiène et assainissement des Villes. Paris, 1874, page 316.*

from our factories. In fact, this foul material coming from establishments employing a large number of operatives is likely, in many cases, to have a more injurious effect upon the stream into which it is thrown, than the refuse from the manufacturing operations. There are, however, some branches of industry which discharge refuse material, offensive and dangerous to health. Such material is discharged from tanneries, wool-pulling and hide-dressing establishments, slaughter-houses and rendering-houses. Too much stress cannot be laid upon the importance of preventing the discharge of such refuse, and of sewage in its more restricted sense, into any stream or pond used, or likely to be used, as a source of water-supply.

The importance of this matter is underrated for two reasons : first, because of the oft-repeated assertion, made on the authority of Dr. Letheby, that " if sewage-matter be mixed with twenty times its bulk of ordinary river-water, and flow a dozen miles, there is not a particle of that sewage to be discovered by chemical means ; " secondly, because of the feeling that to be in any way prejudicial to health, a water must contain enough animal matter to be recognized readily by chemical tests, — enough, in fact, to be expressed in figures.

The first of these opinions has been disproved by the experiments of the Rivers Commission, in England, who have shown that not only is a flow of twelve miles insufficient to destroy the organic matter of sewage when mixed with water in the above proportion, but also a flow of one hundred and sixty miles is far from sufficing for that purpose. When sewage is mixed with water, some of its constituents begin to decompose very soon. The urea, for example, is quickly converted into carbonate of ammonium ; others of the constituents, however, are less ready to begin to decompose, and when decomposition does set in, although some of the substances may undergo chemical change, there still remain or-

ganic nitrogenous compounds in the mixture, and these substances are swept along by the rivers, even to the sea.

The carcass of a dead animal thrown into a river or into a pond, and confined there so as not to be borne off bodily, gradually wastes away, and in a longer or shorter time the main part of the carcass has disappeared. What has become of it? A part has been converted into gaseous products of decomposition as the offensive odors observed during the decay will testify, but another portion has been carried off by the stream as soluble nitrogenous organic matter. This nitrogenous matter would be detected a short distance away with greater or less ease according to the volume of water present, and in a stream of large size or in a lake, at no very great distance from the source of contamination, it would be impossible to discover any offensive matter. There is a limit to the delicacy of our tests; there is a point beyond which, at the present, we are not able to go. At the present time a chemical analysis *alone* is not sufficient to determine the desirability of a given water-supply. The rice-water evacuations of a cholera patient diluted with no very large amount of water would form a liquid in which chemical tests would fail to indicate the presence of anything which could be pronounced injurious, and yet there is no destruction of the poisonous material; it is still in the liquid, although not to be recognized, and such water is now regarded by physicians as the most direct and certain vehicle for the transmission of Asiatic cholera.

The second opinion is that sewage, if diluted to a very considerable extent, becomes innocuous; this opinion, which involves questions belonging to the physician rather than to the chemist, is very likely to be carried too far. I do not know that we have any proof that perfectly fresh sewage (the term being used in its more restricted sense) coming from healthy persons, when mixed with water, is injurious if drank; it would probably not be asserted that such a mixture was



actually good to drink, — it would certainly be opposed to our instinctive ideas. It is true that fish are not destroyed by even a considerable discharge of fresh sewage into a stream. We do know, however, that sewage which has begun to undergo decomposition is unwholesome; such decomposing sewage has been observed to destroy and drive away the fish from the stream in the immediate neighborhood of the point of discharge, and there are a great number of instances on record where cases of sickness have been traced directly to the fact that the water used for drinking was rendered foul by the decomposing excremental matter which found its way into the source of supply; and drinking-water, polluted by even an infinitesimal amount of excremental matter coming from those suffering from typhoid fever, is now very generally held to be capable of propagating that disease.

It has already been stated that sewage-matter itself is not completely destroyed when it is introduced into a running stream, and is borne along even for many miles; we must suppose, and indeed have every reason to believe, that in the case of sewage which when *fresh* is capable of communicating disease, the destruction of the peculiar organized matter which has the specific effect must be more slow even than the unorganized effete matter which forms the mass of the dissolved and suspended solid matter of ordinary sewage. In the case of certain diseases, which have been shown by experiment to owe their origin to the presence of distinct and recognizable living organisms, it has been found that these organisms retain their vitality in spite of very varied conditions, and through very considerable changes of temperature.

One would not assert that the drainage from a single house would contaminate the water of a large river like the Merri-mack so as to make it unfit for domestic use, yet we must beware how we depreciate the effect of sewage-matter, even in a large stream. While, with a small amount of sewage, the chances are as favorable as possible for the action of atmos-



pheric influences, and the chances of taking up any undecomposed particle of material, capable of propagating disease, are rendered proportionally small owing to the great dilution, it is to be borne in mind that the action of such matter on the system is not regarded as *cumulative*. A minute quantity may do much harm, because it is now generally believed that it may hold the specific thing which propagates specific diseases. In the case of certain organic poisons which affect the system through the blood, the experiments of M. Chauveau and of Dr. Burdon-Sanderson on vaccine matter render it well-nigh certain that no amount of dilution can destroy the power of infection which these poisons possess. From these experiments, it appears that if inoculation be performed with vaccine lymph after it has been very much diluted, the chance of the formation of pustules is rendered less, but when the vaccination is successful, the pustule formed presents its normal features and passes through the usual stages of development.

Let us consider for a moment the condition of the Blackstone river. No one could be found who would drink the water of Mill brook; no one probably who would drink the water of the Blackstone at the bridge below Quinsigamond Village, Worcester. When, then, does the water become potable? I do not believe it becomes potable at all, or that it is in its course ever free from the contamination it receives above. The water is, however, sometimes drank at Blackstone and below, and was proposed at one time as an available supply for the city of Providence, R. I.

It has been objected that it would be impossible to obtain water perfectly pure, and that it is very questionable whether perfectly pure water would really be as wholesome as water containing a certain amount of foreign substances (see note on pp. 110, 111). It may be very true that we cannot procure absolutely pure water; we may not even be able to procure water absolutely free from such substances as we regard as injurious; but there are some causes of contamination which

must, at any cost, be avoided, and in other respects the water must be obtained, as nearly as possible, of the ideal excellence. We know that there are many persons who live and seem to get along very well in utter disregard of the laws of health, as far as personal cleanliness, diet, pure air, and many other things are concerned; but because many thus live for a time without experiencing evident inconvenience, does any one argue that purity of air, a healthful diet, and cleanliness of person, are not to be recommended and sought after? The effect upon the community of the bolting of indigestible food must be immense, but comparatively few are the acknowledged cases of injurious effects. We are able, however, in many cases, to show even in these matters that the apparent strength and immunity from discomfort is due to a constitution naturally strong, and the draught upon the vital energy may be seen, if not in the persons themselves in later years, at least in their children.

In fact, to isolate the effects of various habits, which, from a hygienic stand-point, are decidedly bad, is a problem which, in many cases, it is impossible to solve, and yet that disease does come from the use of an inferior water-supply, is abundantly proved by many instances which are on record, where a disease, such as diarrhœa, dysentery, cholera or typhoid fever, which had affected an entire community, has been checked by a change in the source of drinking-water; and on a still larger scale there are instances where the benefits derived from the change to a better water-supply have been marked by a decreased death-rate. In such cases it is difficult to point to the exact thing which has produced the bad effects, but in some cases the presence of a comparatively large amount of organic matter, derived from animal sources, has been the only circumstance to which chemical examination could point as a probable cause.

It is also, as has already been said, well established that particular forms of disease may be and are transmitted by

drainage into wells and other sources of water-supply, and it is impossible to say how little foul matter is needed to work evil effects. A case, or several cases, of typhoid fever in a family, leads to the discovery that the well from which the drinking-water is taken is in underground but direct communication with the vault or cesspool; but the effect upon the system during the time when the well was deteriorating, during the time that the sewage material was gradually wearing a channel to the well, the point of time when the well *began to be* impure, these things were not, could not be noticed.

While for many of the purposes of the household a water unfit for drinking might not be objectionable, we are still obliged to provide for the most exacting of its uses. The time may come when it will be necessary to supply our drinking-water from some sedulously guarded but limited source of supply, and to furnish for manufacturing uses, for the extinguishing of fires, and for the carrier of waste material, a water of poorer quality, but abundant in quantity. The amount of water which we drink is very small compared with that used for other purposes. It is to be hoped and expected that before such necessity arises, it will not only be possible, but financially profitable, to dispose of the refuse materials in other ways than by running them into the water-courses.

Such division of the water-supply is carried out to a certain extent in some places. Paris, for instance, draws its water-supply from various sources, among others from the highly polluted Seine. It has been proposed to reserve for domestic uses a supply drawn from purer sources, and to devote the more impure waters to public uses, such as the supplying the fountains of the various parks, the cleansing of the streets, and the extinguishing of fires. At present, however, the plan is only partly carried out, and much of the water drunk is entirely unfit for such use.

While the chief objection to rivers as sources of water-

supply lies in the fact that they are almost of necessity converted to a greater or less extent into carriers of sewage, it is to be noted that there is a great difference between various streams in their natural conditions, and while a stream like the Merrimack would, from the nature of its water-shed, be well fitted for use, other streams, such as the Charles and the Sudbury or Concord, are much less desirable on account of the soluble vegetable matter which communicates some disagreeable color and taste. This vegetable matter is generally considered as harmless; it no doubt does not have as injurious an effect as sewage-matter, and yet many persons are affected by it. Experience has shown that waters may be freed from much of this color, by storage in reservoirs or ponds exposed to the sun and air.

#### THE PRESENT CONDITION OF THE WATER-SUPPLY OF CERTAIN CITIES IN MASSACHUSETTS.

By what has already been said in the last Annual Report of the Board, and in the preceding pages of the Report, attention is called to the necessity of carefully protecting our lakes and great ponds from defilement, on the ground of the close dependence of the present and future health of the crowded cities and towns of Massachusetts upon the preservation of these reservoirs of pure water for domestic purposes.\*

Attention has been further called † to the special danger threatening the water-supply of Boston (Lake Cochituate), and of East Boston, Charlestown, Chelsea and Somerville (Mystic lake), and it has been thought best by the Board to institute a direct inquiry into the present condition of the water-supply derived from these sources and the prospects for the future.

\* See Fourth Annual Report of the Massachusetts State Board of Health, p. 11.

† Id., p. 105.

*Cochituate.* — It had been noticed that the water, as delivered in the city, possessed more color than formerly, and, although the analyses made at different times differed considerably from each other, yet it seemed that the relative proportion of organic matter had increased.

An examination has been made during the present year of the sources of supply of the lake, and water taken from different points and at different times has been submitted to chemical investigation. The water, as delivered in Boston, has also been the subject of examination at more or less frequent intervals.

Cochituate lake is situated in Middlesex County, in the towns of Natick, Framingham and Wayland. It virtually consists of three lakes or ponds connected together, and is about three and a half miles in length. The banks of the lake in the main are sandy or gravelly, and the water has been of very great purity. The accompanying map will show with sufficient accuracy the general features of the lake, and the position of the various streams and ponds which contribute to the supply of water: —





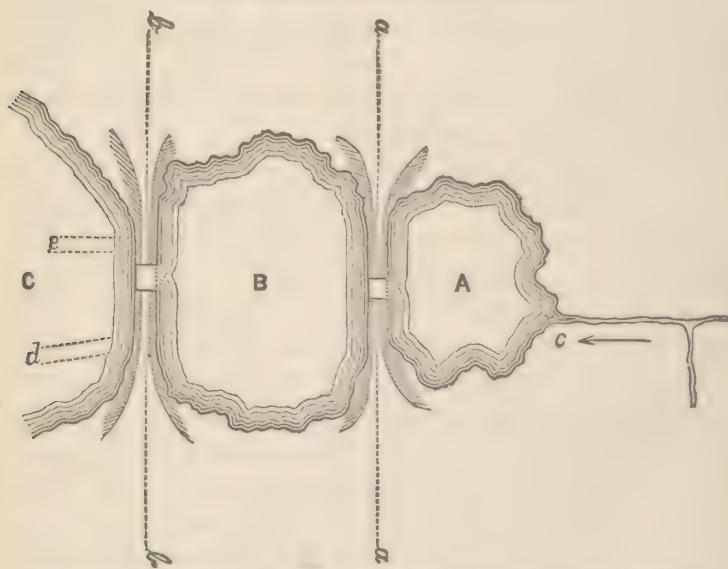
in both these ponds is good. A stream of considerable size, Snake brook, enters the lake near the gate-house. It receives no sensible contamination, although at certain times the water has some considerable color, owing to the meadow-land through which it flows. Beaver Dam brook serves to connect Farm pond with the lake. The water taken during the year 1872 from the Sudbury river was let into Farm pond, and it flowed thence to Cochituate. On the map the point where the dam for diverting the river-water was built is indicated by the letter A.

The only stream which, at the present time, brings down any considerable amount of impurity into the lake is a brook called Pegan's brook, which flows through the centre of the town of Natick, receiving drainage from dwellings on its bank, and also from several factories.

The report of the Cochituate Water Board for the year 1864 alludes to the fact that this brook receives much offensive matter, and in order to intercept it as much as possible, the following plan was adopted, namely: "To build across the meadow, which is from 80 to 100 feet wide at the mouth of the brook, a dam of such materials that the waters of the brook, under a slight head, should filter through, thus arresting much of the filth which would otherwise pass into the lake. A plan was proposed for a dam to be built of common field-stone, except a place three feet in width in the centre of the embankment, extending its whole length, to be filled with fine pebbles or screened gravel, which may be replaced whenever the filter becomes foul or clogged, without disturbing the rest of the dam. To provide for unusual flows of water, as in the case of spring freshets, a flume five feet in width, provided with stop-planks, was to be built through the dam." This plan was carried out originally as a temporary expedient, and a route was surveyed for diverting the waters of the brook to Bannister's brook, which empties into Sudbury river below the point where connection is made

with Farm pond. As this would require the construction of an aqueduct two and a half miles long, and involve an expense of \$70,000, it was felt that the work should not be undertaken except in the event of absolute necessity. The dam was rebuilt in 1867, and a second one, inside of the first, and some eighty feet distant, was built in 1870. The arrangement of these filter-dams may be seen on the accompanying plan, which is intended merely to give an idea of relative position, and is not drawn to scale.

FILTER-DAMS AT MOUTH OF PEGAN BROOK.



*a a, b b*, represent the dams. *A, B*, are the settling-basins. *C* is a portion of the lake.

Pegan brook is joined by another brook in the meadow, but the waters of this brook are usually diverted into Dug pond.

In this connection it may be further stated that outside of the filter-dams, at some distance from them, the waters of the arm of the lake, into which Pegan brook enters, are in part

cut off from the rest of the lake by a bar of gravel which extends from shore to shore, as indicated in the map on page 122, where also may be seen the relative position of the mouth of Pegan brook (indicated by the letter C) with reference to the lake. There is through this gravel-bar a channel, the width of which varies with the height of the water; when the water of the lake is four feet below high water, the channel is about thirty feet wide.

With regard to the efficiency of the means thus adopted for preventing the entrance into the lake of the offensive matters brought down into the settling-basins: At the time of a visit to the lake, made May 16, 1873, there was a considerable amount of water flowing in the brook; the presence of a large number of broken and useless household utensils along the banks, and the decaying carcass of a cat lying in the stream and making the air in the immediate vicinity offensive, showed that the brook was regarded as a natural receptacle for rubbish. The water in both the settling-basins was somewhat turbid and disagreeable to look upon. Outside of the outer embankment the water was somewhat clearer. At this time the water in the lake was at high-water mark, and the water inside the outer embankment was about two feet above the water of the lake. Samples of water taken at the flume inside the inner embankment and outside the outer embankment, showed that, as far as the dissolved impurities were concerned, no amelioration was effected. Subsequent examinations were made at various times during the latter part of the year. The results of the chemical examinations may be found in Tables V. and Va.

On the occasion of personal visits made on July 16 and 21, after a considerable period of dry weather, the stream was found to contain a rather small amount of clear and apparently inoffensive water. The hat-factory, the discharge from which on some occasions causes the water of the brook to be almost black, was not in operation at that time. The water



TABLE V. — Examination of Cochituate Lake and its Sources of Supply. [Results expressed in Parts per 100,000.]

| Number. | DATE.                   | LOCALITY.                                                                                                                                                                                                                                                                                | Ammonia. | "Albuminoid"<br>Ammonia. | SOLID RESIDUE OF UN-<br>FILTERED WATER. |                             |        | SOLID RESIDUE OF FIL-<br>TERED WATER. |                             |        | Chlorine. |
|---------|-------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|--------------------------|-----------------------------------------|-----------------------------|--------|---------------------------------------|-----------------------------|--------|-----------|
|         |                         |                                                                                                                                                                                                                                                                                          |          |                          | Inor-<br>ganic.                         | Organic<br>and<br>Volatile. | Total. | Inor-<br>ganic.                       | Organic<br>and<br>Volatile. | Total. |           |
| 11      | 1873 — May 26 . . . . . | <i>Pegan Brook.</i><br>At the end of covered con-<br>duit . . . . .<br>Just before entering settling-<br>basin . . . . .<br>From first settling-basin . .<br>From second settling-basin.<br>Inside of outer embank-<br>ment . . . . .<br>From outside of outer em-<br>bankment . . . . . | 0.1740   | 0.0350                   | .                                       | .                           | .      | 9.50                                  | 6.60                        | 16.10  | 2.40      |
| 87      | August 28 . . . . .     |                                                                                                                                                                                                                                                                                          | 0.0736   | 0.0100                   | .                                       | .                           | .      | 12.84                                 | 5.24                        | 18.08  | 1.84      |
| 75      | July 16 . . . . .       |                                                                                                                                                                                                                                                                                          | 0.0350   | 0.0162                   | .                                       | .                           | .      | 16.20                                 | 5.60                        | 21.80  | 3.10      |
| 88      | August 28 . . . . .     |                                                                                                                                                                                                                                                                                          | 0.0540   | 0.0136                   | .                                       | .                           | .      | 17.40                                 | 5.28                        | 22.68  | 2.64      |
| 204     | December 17 . . . . .   |                                                                                                                                                                                                                                                                                          | 0.0250   | 0.0087                   | .                                       | .                           | .      | 11.24                                 | 3.60                        | 14.84  | 1.84      |
| 4       | May 16 . . . . .        |                                                                                                                                                                                                                                                                                          | 0.0188   | 0.0364                   | .                                       | .                           | .      | 3.90                                  | 4.40                        | 8.30   | 2.25      |
| 10      | " 26 . . . . .          |                                                                                                                                                                                                                                                                                          | 0.2171   | 0.0542                   | .                                       | .                           | .      | 13.50                                 | 12.20                       | 25.70  | 2.80      |
| 41      | July 1 . . . . .        |                                                                                                                                                                                                                                                                                          | 0.1100   | 0.0200                   | .                                       | .                           | 25.60  | 12.90                                 | 5.40                        | 18.30  | 2.92      |
| 76      | " 16 . . . . .          |                                                                                                                                                                                                                                                                                          | 0.0270   | 0.0430                   | .                                       | .                           | .      | 14.32                                 | 2.76                        | 17.08  | 3.04      |
| 9       | May 26 . . . . .        |                                                                                                                                                                                                                                                                                          | 0.1656   | 0.0627                   | .                                       | .                           | .      | 12.70                                 | 10.20                       | 22.90  | 2.80      |
| 77      | July 16 . . . . .       |                                                                                                                                                                                                                                                                                          | 0.1120   | 0.0347                   | .                                       | .                           | .      | 14.80                                 | 2.28                        | 17.08  | 3.26      |
| 3       | May 16 . . . . .        |                                                                                                                                                                                                                                                                                          | 0.0496   | 0.0365                   | .                                       | .                           | .      | 8.20                                  | 9.00                        | 17.20  | 1.25      |
| 8       | " 23 . . . . .          |                                                                                                                                                                                                                                                                                          | 0.0528   | 0.0799                   | .                                       | .                           | .      | 4.90                                  | 2.30                        | 7.20   | 0.70      |
| 42      | July 1 . . . . .        |                                                                                                                                                                                                                                                                                          | 0.0275   | 0.0231                   | .                                       | .                           | 14.00  | 7.40                                  | 1.20                        | 8.60   | 1.50      |



|     |                       |                                 |        |        |       |      |       |      |       |      |
|-----|-----------------------|---------------------------------|--------|--------|-------|------|-------|------|-------|------|
| 78  | July 16 . . . . .     | From brook issuing from {       | 0.1000 | 0.0230 | ..    | ..   | 14.40 | 2.52 | 10.92 | 3.32 |
| 89  | August 23 . . . . .   | southern end of outer em- {     | 0.0070 | 0.0450 | 15.60 | 6.36 | 21.96 | 5.20 | 20.00 | 2.64 |
| 203 | December 17 . . . . . | bankment <sup>1</sup> . . . . . | 0.0193 | 0.0060 | ..    | ..   | 12.64 | 1.60 | 14.24 | 2.00 |
| 90  | August 23 . . . . .   | From brook issuing from {       | 0.0120 | 0.0240 | ..    | ..   | 14.16 | 5.12 | 10.28 | 2.68 |
|     |                       | centre <sup>2</sup> . . . . .   |        |        |       |      |       |      |       |      |
| 43  | July 1 . . . . .      | <i>Cochituate Lake.</i>         | 0.0127 | 0.0320 | ..    | ..   | 9.20  | 2.30 | 7.30  | 0.63 |
| 79  | " 16 . . . . .        | From channel in bar (see {      | 0.0080 | 0.0250 | ..    | ..   | 3.80  | 3.32 | 7.12  | 0.76 |
| 96  | August 29 . . . . .   | description) . . . . .          | 0.0067 | 0.0188 | ..    | ..   | 4.40  | 2.80 | 7.20  | 0.44 |
| 202 | December 17 . . . . . |                                 | 0.0160 | 0.0093 | ..    | ..   | 7.00  | 2.60 | 9.60  | 1.04 |
| 5   | May 16 . . . . .      |                                 | ..     | 0.0234 | ..    | ..   | ..    | ..   | 4.40  | 0.40 |
| 12  | " 26 . . . . .        | Bridge over Saxonville Br'ch {  | 0.0160 | 0.0360 | ..    | ..   | ..    | ..   | 4.50  | 0.40 |
| 80  | July 16 . . . . .     | Railroad . . . . .              | 0.0040 | 0.0127 | ..    | ..   | 2.28  | 1.76 | 4.04  | 0.40 |
| 91  | August 29 . . . . .   |                                 | 0.0033 | 0.0208 | ..    | ..   | 3.24  | 3.36 | 6.60  | 0.38 |
| 14  | May 26 . . . . .      | Bridge near gate-house . . {    | 0.0160 | 0.0240 | ..    | ..   | 2.00  | 2.20 | 4.20  | 0.35 |
| 92  | August 29 . . . . .   |                                 | 0.0045 | 0.0153 | ..    | ..   | 2.40  | 1.88 | 4.28  | 0.26 |
| 13  | May 26 . . . . .      | At gate-house . . . . .         | 0.0140 | 0.0390 | ..    | ..   | 1.40  | 2.20 | 3.60  | 0.35 |
| 93  | August 29 . . . . .   |                                 | 3.0033 | 0.0103 | ..    | ..   | 2.92  | 1.72 | 4.64  | 0.28 |
| 94  | " 23 . . . . .        | Inlet from Dudley Pond . . {    | 0.0051 | 0.0193 | ..    | ..   | 2.84  | 1.80 | 4.64  | 0.24 |
| 6   | May 16 . . . . .      | Snake Brook . . . . .           | 0.0016 | 0.0152 | ..    | ..   | 1.90  | 3.30 | 5.20  | 0.35 |
| 95  | August 29 . . . . .   |                                 | 0.0027 | 0.0140 | ..    | ..   | 4.68  | 1.64 | 6.32  | 0.28 |
| 44  | July 1 . . . . .      | Beaver Dam Brook . . . . {      | 0.0074 | 0.0193 | ..    | ..   | 4.50  | 3.00 | 7.50  | 0.36 |
| 45  | " 1 . . . . .         | Outlet of Farm Pond . . .       | 0.0096 | 0.0133 | ..    | ..   | 5.70  | 0.70 | 6.40  | 0.38 |

<sup>1</sup> See *d*, p. 122.<sup>2</sup> See *e*, p. 122.

TABLE V. — *Examination of Cochituate Lake and its Sources of Supply.* [Results expressed in Parts per 100,000.] — *Continued.*

| Number. | DATE.                 | LOCALITY.                                                                       | Ammonia. | SOLID RESIDUE OF UN-FILTERED WATER. |                       |        | SOLID RESIDUE OF FIL-TERED WATER. |                       |        | Chlorine. |
|---------|-----------------------|---------------------------------------------------------------------------------|----------|-------------------------------------|-----------------------|--------|-----------------------------------|-----------------------|--------|-----------|
|         |                       |                                                                                 |          | Inor-ganic.                         | Organic and Volatile. | Total. | Inor-ganic.                       | Organic and Volatile. | Total. |           |
| .       | June 30 . . . . .     | Boston. Laboratory of the<br>Massachusetts Institute of<br>Technology . . . . . | .        | .                                   | .                     | .      | 2.20                              | 2.30                  | 4.50   | 0.32      |
| .       | July 4 . . . . .      |                                                                                 | 0.0033   | .                                   | .                     | .      | 2.84                              | 2.80                  | 5.64   | 0.34      |
| .       | September 6 . . . . . |                                                                                 | 0.0040   | .                                   | .                     | .      | 2.76                              | 2.06                  | 4.82   | 0.30      |
| .       | " 15 . . . . .        |                                                                                 | 0.0033   | .                                   | .                     | .      | 2.40                              | 1.90                  | 4.30   | 0.31      |
| .       | October 6 . . . . .   |                                                                                 | 0.0033   | .                                   | .                     | .      | 3.24                              | 1.96                  | 5.20   | 0.34      |
| .       | " 25 . . . . .        |                                                                                 | 0.0034   | .                                   | .                     | .      | 2.36                              | 2.40                  | 4.76   | 0.32      |
| .       | November 15 . . . . . |                                                                                 | 0.0033   | .                                   | .                     | .      | 3.00                              | 2.00                  | 5.00   | 0.30      |
| .       | December 19 . . . . . |                                                                                 | 0.0037   | .                                   | .                     | .      | 3.32                              | 1.28                  | 4.60   | 0.34      |
|         |                       |                                                                                 |          | "Albuminoid"<br>Ammonia.            |                       |        |                                   |                       |        |           |
|         |                       |                                                                                 |          | 0.0149                              |                       |        |                                   |                       |        |           |
|         |                       |                                                                                 |          | 0.0120                              |                       |        |                                   |                       |        |           |
|         |                       |                                                                                 |          | 0.0120                              |                       |        |                                   |                       |        |           |
|         |                       |                                                                                 |          | 0.0120                              |                       |        |                                   |                       |        |           |
|         |                       |                                                                                 |          | 0.0120                              |                       |        |                                   |                       |        |           |
|         |                       |                                                                                 |          | 0.0080                              |                       |        |                                   |                       |        |           |
|         |                       |                                                                                 |          | 0.0132                              |                       |        |                                   |                       |        |           |
|         |                       |                                                                                 |          | 0.0100                              |                       |        |                                   |                       |        |           |

TABLE V. a.—*Examination of Cochituate Lake and its Sources of Supply.* [Results expressed in Grains per U. S. Gallon.]

| Number. | DATE.               | LOCALITY.                                                                                                                                                                                                                                                                                | Ammonia. | "Albuminoid."<br>Ammonia. | SOLID RESIDUE OF UN-<br>FILTERED WATER. |                             |        | SOLID RESIDUE OF FIL-<br>TERED WATER. |                             |        | Chlorine. |
|---------|---------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|---------------------------|-----------------------------------------|-----------------------------|--------|---------------------------------------|-----------------------------|--------|-----------|
|         |                     |                                                                                                                                                                                                                                                                                          |          |                           | Inor-<br>ganic.                         | Organic<br>and<br>Volatile. | Total. | Inor-<br>ganic.                       | Organic<br>and<br>Volatile. | Total. |           |
| 11      | 1873—May 26 . . . . | <i>Pegan Brook.</i><br>At end of covered conduit }<br>Just before entering set- }<br>tling-basin . . . . . }<br>From first settling-basin . }<br>From second settling-ba- }<br>sin. Inside of outer em- }<br>bankment . . . . . }<br>From outside of outer em- }<br>bankment . . . . . } | 0.1018   | 0.0204                    | . .                                     | . .                         | . .    | 5.54                                  | 3.85                        | 9.39   | 1.40      |
| 87      | August 23 . . . .   |                                                                                                                                                                                                                                                                                          | 0.0430   | 0.0058                    | . .                                     | . .                         | . .    | 7.49                                  | 3.06                        | 10.55  | 1.07      |
| 75      | July 16 . . . . .   |                                                                                                                                                                                                                                                                                          | 0.0204   | 0.0094                    | . .                                     | . .                         | . .    | 9.43                                  | 3.27                        | 12.70  | 1.81      |
| 88      | August 28 . . . .   |                                                                                                                                                                                                                                                                                          | 0.0315   | 0.0079                    | . .                                     | . .                         | . .    | 10.16                                 | 3.08                        | 13.26  | 1.54      |
| 204     | December 17 . . . . |                                                                                                                                                                                                                                                                                          | 0.0146   | 0.0051                    | . .                                     | . .                         | . .    | 6.56                                  | 2.70                        | 8.66   | 1.07      |
| 4       | May 16 . . . . .    |                                                                                                                                                                                                                                                                                          | 0.0110   | 0.0212                    | . .                                     | . .                         | . .    | 2.28                                  | 2.57                        | 5.85   | 1.31      |
| 10      | " 23 . . . . .      |                                                                                                                                                                                                                                                                                          | 0.1267   | 0.0316                    | . .                                     | . .                         | . .    | 7.88                                  | 7.12                        | 15.00  | 1.63      |
| 41      | July 1 . . . . .    |                                                                                                                                                                                                                                                                                          | 0.0642   | 0.0117                    | . .                                     | . .                         | 14.94  | 7.53                                  | 3.15                        | 10.68  | 1.70      |
| 76      | " 16 . . . . .      |                                                                                                                                                                                                                                                                                          | 0.0158   | 0.0251                    | . .                                     | . .                         | . .    | 8.86                                  | 1.61                        | 9.97   | 1.77      |
| 9       | May 26 . . . . .    |                                                                                                                                                                                                                                                                                          | 0.0969   | 0.0366                    | . .                                     | . .                         | . .    | 7.41                                  | 5.95                        | 13.36  | 1.63      |
| 77      | July 16 . . . . .   |                                                                                                                                                                                                                                                                                          | 0.0654   | 0.0203                    | . .                                     | . .                         | . .    | 8.64                                  | 1.33                        | 9.97   | 1.90      |
| 3       | May 16 . . . . .    |                                                                                                                                                                                                                                                                                          | 0.0255   | 0.0213                    | . .                                     | . .                         | . .    | 4.79                                  | 5.25                        | 10.04  | 0.73      |
| 8       | " 26 . . . . .      |                                                                                                                                                                                                                                                                                          | 0.0308   | 0.0466                    | . .                                     | . .                         | . .    | 2.86                                  | 1.34                        | 4.20   | 0.41      |
| 42      | July 1 . . . . .    |                                                                                                                                                                                                                                                                                          | 0.0160   | 0.0135                    | . .                                     | . .                         | 8.17   | 4.32                                  | 0.70                        | 5.02   | 0.88      |

TABLE V.a.—*Examination of Cochituate Lake and its Sources of Supply.* [Results expressed in Grains per U. S. Gallon.] — *Continued.*

| Number. | DATE.           | LOCALITY.                                                                                                                                                                 | Ammonia. | "Albuminoid."<br>Ammonia. | SOLID RESIDUE OF UN-<br>FILTERED WATER. |                             |        | SOLID RESIDUE OF FIL-<br>TERED WATER. |                              |        | Chlorine. |
|---------|-----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|---------------------------|-----------------------------------------|-----------------------------|--------|---------------------------------------|------------------------------|--------|-----------|
|         |                 |                                                                                                                                                                           |          |                           | Inor-<br>ganic.                         | Organic<br>and<br>Volatile. | Total. | Inor-<br>ganic.                       | (Organic<br>and<br>Volatile. | Total. |           |
| 78      | 1873—July       | <i>Pegan Brook.</i><br>From brook issuing from<br>southern end of outer<br>embankment <sup>1</sup> . . . . .<br>From brook issuing from<br>centres <sup>2</sup> . . . . . | 0.0584   | 0.0134                    | .                                       | .                           | .      | 8.40                                  | 1.47                         | 9.87   | 1.94      |
| 89      | August          |                                                                                                                                                                           | 0.0041   | 0.0262                    | 9.11                                    | 3.71                        | 12.82  | 8.64                                  | 3.04                         | 11.68  | 1.54      |
| 203     | December 17 . . |                                                                                                                                                                           | 0.0113   | 0.0035                    | .                                       | .                           | .      | 7.38                                  | 0.93                         | 8.31   | 1.17      |
| 90      | August          |                                                                                                                                                                           | 0.0070   | 0.0140                    | .                                       | .                           | .      | 8.25                                  | 2.99                         | 11.25  | 1.56      |
| 43      | July            | <i>Cochituate Lake.</i><br>From channel in bar (see<br>description . . . . .                                                                                              | 0.0074   | 0.0187                    | .                                       | .                           | .      | 2.92                                  | 1.34                         | 4.26   | 0.39      |
| 79      | "               |                                                                                                                                                                           | 0.0047   | 0.0146                    | .                                       | .                           | .      | 2.22                                  | 1.94                         | 4.16   | 0.44      |
| 96      | August          |                                                                                                                                                                           | 0.0039   | 0.0110                    | .                                       | .                           | .      | 2.57                                  | 1.63                         | 4.20   | 0.26      |
| 202     | December 17 . . |                                                                                                                                                                           | 0.0093   | 0.0054                    | .                                       | .                           | .      | 4.09                                  | 1.52                         | 5.61   | 0.61      |
| 5       | May             | Bridge over Saxonville<br>Branch Railroad . . . .                                                                                                                         | ...      | 0.0137                    | .                                       | .                           | .      | .                                     | .                            | 2.57   | 0.23      |
| 12      | "               |                                                                                                                                                                           | 0.0093   | 0.0210                    | .                                       | .                           | .      | .                                     | .                            | 2.62   | 0.23      |
| 80      | July            |                                                                                                                                                                           | 0.0023   | 0.0074                    | .                                       | .                           | .      | 1.33                                  | 1.03                         | 2.36   | 0.33      |
| 91      | August          |                                                                                                                                                                           | 0.0019   | 0.0121                    | .                                       | .                           | .      | 1.89                                  | 1.96                         | 3.85   | 0.22      |

[illegible]

2 See e, p. 122.

1 See *d.*, p. 122.



in the first settling-basin contained a large amount of confervæ, so as to be green and opaque in appearance; the second basin was of the same green color at the upper end; towards the lake it was turbid, but the turbidity was more of a clayey color. At this time the water in the lake was some three feet below high-water mark, and the whole of the outer face of the outer embankment was dry. The water within the embankment stood at two feet or more higher than on the outside. From the southern end of the embankment issued a small, clear stream (*d*, p. 122), about equal in size to that which entered the upper basin, and, as appeared on chemical examination, even more impure, owing, no doubt, to the fact of its carrying off a portion of the matter which had previously collected in the basins. There is no doubt that the filter-dams may and do arrest and retain a considerable amount of filth which would otherwise find its way into the lake. The filth retained, however, is matter which is insoluble, and the deposit has to be removed occasionally; the effect on the dissolved organic matter is so extremely slight as to be of almost no account. This is, to be sure, what would be expected *à priori*, as filtration through a bed of gravel or sand saturated with water, and kept in such condition, could not be expected to remove the organic matter in solution.

It is to be observed that the examination made in December showed more satisfactory results, although in this case the character of the organic matter was very objectionable. At this time, also, the amount of dissolved oxygen was much greater than in the summer, as will be seen on the following page. It will be observed also that, at this time, the effect of the brook upon the water at the bar was greater than at the time of previous examinations.

The heights of the water in the lake at the time the samples were taken were as follows, according to figures kindly furnished by Mr. D. Fitzgerald, Superintendent of the Western Division: —

|                   | Above bottom of<br>Aqueduct. | Boston High-<br>water Mark. |
|-------------------|------------------------------|-----------------------------|
| May 12 . . . . .  | 13ft. 4 in.                  | 0ft. in.                    |
| 16 . . . . .      | 13 1½                        | 0 2½                        |
| July 1 . . . . .  | 11 1½                        | 2 8                         |
| 16 . . . . .      | 10 2½                        | 3 1½                        |
| Aug. 28 . . . . . | 8 8½                         | 4 7½                        |
| Dec. 17 . . . . . | 9 4                          | 4 0                         |

On August 29, determinations were made on the spot of the amount of oxygen dissolved in water, with the following results :—

|                                                                | OXYGEN.                                    |                                   |
|----------------------------------------------------------------|--------------------------------------------|-----------------------------------|
|                                                                | In cubic centi-<br>meters to the<br>liter. | In cubic inches<br>to the gallon. |
| Pegan Brook, just before entering the first settling-basin .   | 1.91                                       | 0.44                              |
| First settling-basin, lower end . . . . .                      | 1.06                                       | 0.24                              |
| Second settling-basin, upper end . . . . .                     | 1.49                                       | 0.34                              |
| Second settling-basin, lower end . . . . .                     | 1.66                                       | 0.38                              |
| Brook issuing from southern end ( <i>d</i> , p. 122) . . . . . | 1.42                                       | 0.33                              |
| Brook issuing at centre ( <i>e</i> , p. 122) . . . . .         | 1.31                                       | 0.30                              |
| Lake at outer bar . . . . .                                    | 3.78                                       | 0.87                              |

On December 18, determinations were made of the amount of oxygen contained in the water of Pegan brook, the stream issuing from the dam, and of the water in the lake. The waters were taken on December 17 at noon, and at that time were of a temperature not far from the freezing-point. The bottles in which they were taken were not opened until the succeeding morning. The oxygen was then determined, the waters being of the temperature in each case as indicated below—

| Number. | LOCALITY.                      | Temperature in<br>centigrade de-<br>grees. | Oxygen in cubic<br>centimeters to<br>liter. | Temperature in<br>Fahrenheit<br>degrees. | Oxygen in cubic<br>inches to the<br>gallon. |
|---------|--------------------------------|--------------------------------------------|---------------------------------------------|------------------------------------------|---------------------------------------------|
| 204     | Pegan Brook . . . . .          | 16°                                        | 7.8                                         | 61°                                      | 1.80                                        |
| 208     | Stream issuing from dam . . .  | 16°                                        | 7.5                                         | 61°                                      | 1.73                                        |
| 202     | Lake, channel in bar . . . . . | 16°                                        | 6.6                                         | 61°                                      | 1.52                                        |

This being the state of things with regard to Pegan brook, the question immediately arises, Does the impurity thus entering the lake have any actual effect on the water, as regards its use for domestic purposes? I think we are safe in believing that, at the present moment, there is nothing in the condition of the water, or in its effect upon the systems of those who drink it, which can be charged to Pegan brook. A glance at the map, or at the lake itself, shows the enormous extent to which this impurity would be diluted, even supposing that it reached the consumer unchanged; but the progress of the water from this extreme end of the lake to the gate-house must be exceedingly slow, so that the opportunity for the chemical changes which affect the organic impurities of natural waters, when exposed to the light of the sun and to the oxygen of the air, is as favorable as it could well be. At any rate, the means of analysis at present at our command are insufficient to give us more than a slight suspicion of the presence of animal matter. On page 132 are collected together some of the previously published partial analyses of Cochituate water. As has been stated above, a general agreement will be observed in this respect, viz., that, as a rule, the relative proportion of organic matter has increased. My own examinations show, what is not unnatural, that the variations during the same season may be considerable, and my personal observation does not extend back through a sufficient number of years to lead me to assert that the water of the lake is

less desirable for general use than it *has ever been before*. As far as my observation does extend, the water, as received in Boston during the years 1872 and 1873, has been more strongly colored, and otherwise less pure, than in the two years preceding. The color and the increase in the amount of organic substances seems to be due to the presence of a larger quantity of vegetable matter. To fix absolutely upon the exact causes to which this change is to be attributed, is not possible. That the introduction of Sudbury river has contributed somewhat largely, there is no doubt; during the year 1872 the amount of water taken from the river was estimated at 1,676 million gallons, or about 110 days' supply; during the year 1873 no water has been taken from the river.

Another cause which probably is to be taken into the account is, that the water finding its way to the lake from that portion of its water-shed occupied by the town of Natick is probably less pure than formerly; moreover, during the years 1871-72 the water was very low, at one time even below the bottom of the conduit, and was pumped from the lake; this drain upon the lake and its water-shed probably contributed its share to bring about the general result, and it is possible that the influence of Pegan brook was felt at the same time, not simply from its direct contributions, but from the drainage through the ground fouled by the material which is deposited from it. In this immediate connection it may be instructive to compare together the results obtained at various times from the examination of the water at the bar, which partly shuts off from the lake the waters of the meadow into which Pegan brook empties. (Compare Nos. 43, 79, 96, 202 in Table V. or V.a.) At the time the examination of No. 202 was made, the water in the lake was four feet below high-water mark, and, consequently, a considerable portion of the meadow was not covered with water. It is evident from the examination, that the influence of the material brought down by the Pegan brook was felt more at

this time than previously, owing, no doubt, to the fact that the examination was made after a number of months of comparatively calm water.

| DATE.             | OBSERVER.              | PARTS PER 100,000. |                       |        | GRAINS PER U. S. GALL. |                       |                   |
|-------------------|------------------------|--------------------|-----------------------|--------|------------------------|-----------------------|-------------------|
|                   |                        | Inorganic.         | Organic and Volatile. | Total. | Inorganic.             | Organic and Volatile. | Total.            |
| July 1, 1834 . .  | C. T. Jackson . . .    | . .                | . .                   | 6.00   | . .                    | . .                   | 3.50              |
| May 1, 1837 . .   | A. A. Hayes . . . .    | 2.11               | 0.93                  | 3.03   | 1.23                   | 0.54                  | 1.77              |
| July 15, 1845 . . | B. Silliman, Jr. . . . | 2.09               | 1.08                  | 3.17   | 1.22                   | 0.63                  | 1.85 <sup>1</sup> |
| Sept. 8, 1845 . . | “ . . .                | 3.78               | 1.99                  | 5.77   | 2.21                   | 1.16                  | 3.37 <sup>2</sup> |
| 8, 1845 . .       | “ . . .                | 4.54               | 2.38                  | 6.92   | 2.65                   | 1.39                  | 4.04              |
| 8, 1848 . .       | E. N. Horsford . . .   | 2.90               | 2.45                  | 5.35   | 1.69                   | 1.43                  | 3.12              |
| Dec. 8, 1854 . .  | C. T. Jackson . . .    | 2.59               | 1.84                  | 4.43   | 1.52                   | 1.07                  | 2.59 <sup>3</sup> |
| Feb. 1, 1855 . .  | { “                    | 5.14               | 3.43                  | 8.57   | 3.00                   | 2.00                  | 5.00 <sup>4</sup> |
|                   | { “                    | 5.54               | 2.34                  | 7.88   | 3.23                   | 1.37                  | 4.60 <sup>5</sup> |
|                   | { “                    | 4.14               | 2.03                  | 6.17   | 2.42                   | 1.18                  | 3.60 <sup>6</sup> |
| Dec. 1, 1870 . .  | W. R. Nichols . . .    | 3.08               | 1.12                  | 4.20   | 1.80                   | 0.65                  | 2.45              |
| 1, 1871 . .       | S. Dana Hayes . . .    | 4.06               | 1.42                  | 5.48   | 2.37                   | 0.83                  | 3.20              |
| Oct. 1, 1872 . .  | S. P. Sharples . . .   | 2.01               | 2.78                  | 4.79   | 1.17                   | 1.62                  | 2.79              |
| Dec. 1, 1872 . .  | W. R. Nichols . . .    | 3.00               | 2.30                  | 5.30   | 1.75                   | 1.34                  | 3.09              |

1 Near (proposed) aqueduct.  
5 Middle Pond.

2 Upper division.  
6 Upper Pond.

3 Boston. 4 Lower Pond.

If, at the present time, the water of Cochituate lake is well suited for all domestic uses, is there any well-grounded reason to fear for the future? Decidedly there is. The town of Natick, as stated in the last report of the Board, feels the necessity of a water-supply. Whether this supply be taken from Charles river or from the lake, the *natural* outlet for any system of drains or sewers is to the lake. The introduction of water would, no doubt, soon and rapidly increase



the proportion of filth brought down by Pegan brook, and although the drainage of the more northern portion of the town would probably, for the present, be allowed to soak into the ground, and reach the lake only after an efficient purification, eventually, no doubt, it would find its way by actual drains. Moreover, at the present time, gas-works are being constructed in Natick, directly upon the brook, and the effect of these works will probably be to increase the amount of objectionable matter brought down into the settling-basins. How far this will affect the water of the lake remains to be seen. The discharge of gas-works into streams and ponds, in some instances, has been known to produce bad effects by killing the fish and by destroying the lower forms of animal life, which are important agents in preserving the purity of fresh water.

It is not necessary here to repeat what has already been said, as to the influence in general of sewage on the water of either streams or ponds into which it is allowed to flow; in the case of ponds or lakes, it is extremely important that no sewage-matter should be thrown into them. The changes to which such organic material is subject take place in the pond as in the river, and the destruction of the soluble organic matter is likely to be more complete if any does enter, especially if the water is drawn from the pond at a point distant from that at which it receives foul matters, so that, in a large pond, less immediate effect may be perceived than in the case of a river. The deposit of matter in suspension, which goes on continuously without the chance of removal by freshets, as in the case of rivers, is, however, preparing evil for the future. This deposit undergoes a slow process of decay, but increases continually, and is liable to be stirred up by heavy rains, especially after a dry time, when a portion of the deposit which forms at the point of discharge has been left uncovered by the water. The advantage of an intercepting lake, serving as a settling-basin, in the course of

a polluted stream is great, and the water delivered from the lake in such a case is superior to that received ; the efficiency, however, of such an agent of purification can be but limited, and a portion of its efficiency consists, no doubt, in the fact that it collects water coming from springs and draining from the surrounding country, and thus dilutes the impure with a purer water.

It is from a very strong feeling of the danger of admitting sewage to any source of water-supply, that the hope is expressed that some measures will be devised for legally preventing such accessions. With the existing state of the law it seems impossible to obtain an injunction against such improper use of a water-course or of a pond, unless it can be shown, by actual proof, that the water is rendered unfit for use. It would thus be necessary quietly to observe the gradual deterioration of the water until actual sickness and death of water-takers made an injunction possible, and then the water would have been rendered almost hopelessly impure, and could hardly be brought back to its original state.

The proposed introduction of the water of Sudbury river into Lake Cochituate, or rather the introduction of the river-water in connection with that of the lake into Chestnut-hill reservoir, furnishes another cause for anxiety. The river is not at present, to any considerable extent, the carrier of sewage. From the nature of the stream, it takes up, during the summer and fall, a large quantity of vegetable matters, which give to it a very decided color. Except in excessive amounts this vegetable matter is not reputed unhealthy, and experience has shown that water stored in reservoirs and exposed to light and air is freed, to some extent, from these matters. Although the presence of so large a quantity of vegetable matter renders it somewhat less desirable for general use, the water at the present time seems quite well suited, after storage, for domestic purposes. Its continued fitness, however, depends upon the care with which it is preserved from con-

tamination. The difficulty of preserving any running stream free from contributions of sewage has already been alluded to; the Sudbury river is, however, rather favorably situated, and there is no immediate prospect that there will be a very large population along its valley. At Ashland, a few miles above Framingham, there are extensive but unfinished buildings, which were erected by the "Dwight Print Company" to be used as print-works. The buildings remain unfinished, and, as far as I can learn, there is no immediate prospect of their being put to the use for which they were designed, and if Sudbury river is to serve as a supply for the city of Boston, it is to be hoped they never will go into operation. The volume of water is not so large that the discharge from such an establishment could fail to have an unfavorable influence upon its quality, and the introduction of sewers and drains from the town of Ashland should also be prevented.

Another source of contamination to the waters of the Sudbury river will be that arising from the decomposition of the vegetable matter in the meadows overflowed in the formation of the proposed storage reservoirs (see Report of the Cochituate Water Board on an Additional Supply of Water, 1873, p. 34). The expense of removing the entire accumulation of vegetable matter, and of the peaty soil in which it grows, would be too large to make such a removal practicable, although it would be desirable. The decomposition of the vegetable matter will render the water disagreeable to the taste and unfit for many uses, but the effect, to judge from experience in other places, will be temporary.\*

The growth of South Framingham and its approach to the shores of Farm pond, through which the waters of Sudbury river have been diverted, and which is connected with Cochituate lake, afford further cause for anxiety. Little if any

\* Prof. Silliman cites a remarkable instance of this in the case of New Britain, Conn. See his Report on the Water-Supply from Upper Mystic Pond, Charlestown, 1862, p. 29.

water has been drawn the present year from Farm pond, but in view of its situation, and the possibility of its use, either permanently or occasionally, it should be jealously protected from any discharge of sewage matter.

In connection with the examination into the character of the Boston water-supply, the following more complete analysis was made of Cochituate water in Boston, July 4, 1873 :

|                                                                  | Parts<br>per 100,000. | Grains<br>per gallon. |
|------------------------------------------------------------------|-----------------------|-----------------------|
| Ammonia . . . . .                                                | 0.0033                | 0.0019                |
| "Albuminoid ammonia" . . . . .                                   | 0.0120                | 0.0070                |
| Inorganic . . . . .                                              | 2.84                  | 1.66                  |
| Organic and volatile . . . . .                                   | 2.80                  | 1.63                  |
| Total dissolved matters . . . . .                                | 5.64                  | 3.29                  |
| Chlorine . . . . .                                               | 0.34                  | 0.20                  |
| Sulphuric acid ( $\text{SO}_3$ ) . . . . .                       | 0.91                  | 0.53                  |
| Silica . . . . .                                                 | 0.28                  | 0.16                  |
| Alumina Oxide of Iron (with traces of phosphoric acid) . . . . . | 0.85                  | 0.50                  |
| Lime . . . . .                                                   | 0.42                  | 0.25                  |
| Magnesia . . . . .                                               | 0.06                  | 0.03                  |
| Soda . . . . .                                                   | 0.17                  | 0.10                  |
| Potash . . . . .                                                 | 0.25                  | 0.15                  |
| Carbonic acid . . . . .                                          | Undetermined.         | ..                    |

*Mystic Water.*—The sources of supply, from which is derived the water of the Mystic lake, are very much inferior to those of Cochituate Lake. Before the use of the waters of the lake to supply the city of Charlestown, its tributaries were already used as a receptacle for the foul refuse of various manufacturing establishments, and the amount of this material has increased up to the present time. An examination of several of the ponds and streams which contribute to the Mystic supply was made by the writer in 1870, and at that



time it was not felt that anything in the condition of the water, as delivered at Charlestown, could be traced to these manufacturing establishments. It was, however, very strongly felt that this was a source of danger, and that except some remedy were found it would, in the course of time, bring about a very sensible deterioration of the waters of the lake.

The lake itself is less favorably situated than Cochituate; its main direct supply is afforded by the Abajonna river, which brings down refuse from a number of tanneries and other establishments. At Winchester, where it expands to a pond, it is joined by another stream, which serves as an outlet to the waters of Horn pond. A map of this region was given in the report of the Board of Health presented in 1871. It will be seen that the distance from the head of the lake to the town of Winchester is very short, and Winchester numbers already 2,645 inhabitants (census of 1870).

Although, from personal observation made since 1870, it seemed evident that the condition of things was no better than at that time, it was thought best to take several series of samples during the present year, and to submit them to chemical examination. With this view the examinations, the results of which are incorporated in Tables VI. and VI.a, were made in June, and it was our intention to investigate the matter further later in the season, but the prospect of a thorough investigation by the city of Boston delayed our action, and when a special commission was appointed by the city to take the whole subject into consideration, it was decided on our part to pursue it no further. I, therefore, early in November, communicated the results already obtained to the Secretary of the Board, with the hope that the influence of the discharge from the tanneries, glue-factories, etc., might be thoroughly investigated. Having had occasion during the past summer to pass many times along the Abajonna river, and to observe the water in the stream and in



the pond at Winchester, I could not but be impressed with the danger of allowing so small a stream of water to be contaminated with the refuse from so many establishments. There seems but to be one way of efficiently protecting these streams from defilement, and it is by the construction of a sewer which shall collect this objectionable refuse-matter, and convey it to a point below the dam on the Mystic river, or to some other point where it would contaminate no source of water-supply. I am unable to state the engineering difficulties of such a scheme, or the amount of water that would thus be lost to the lake. In the present condition of things I do not think any other plan would be found efficient. It would very likely be possible, and perhaps in some cases advantageous, to purify such refuse by the process of intermittent filtration through natural soil. This process was described in the last report of the Board of Health.

Attempts have been made to dispose of the liquid refuse from some of the tanneries by allowing the liquid to flow into pits, and thence to soak slowly into the gravelly subsoil, the suspended matters which settle out being then removed mechanically. This cannot be regarded in any sense as a satisfactory settlement of the question. As far as I am informed no attempts have been made invoking *intermittent filtration*; that is, the alternate exposure of the soil to the air and to the matter filtered. The disposal of liquid refuse by the cesspool system is not new; attempts have often been made in the same direction before; the effect depends upon the locality chosen. No considerable purification of the liquid (except from suspended matters) is accomplished, and the liquid flows into the ground to contaminate the stream if on the banks of a stream; to pollute the wells, if there are such in the neighborhood; or, if no present injury is brought about, the subsoil becomes saturated with the foul material, which may bring about evil results in the future. The puri-

ifying power of natural soil is not fully understood, but we know that any given soil possesses a certain limit of purifying power, and that if the soil be not intermittently exposed to the air, that limit is soon passed. A considerable amount of a very foul liquid may be run on to even a rather smaller area without offence, and the drainage from this area may also be without offence, provided the flooding takes place intermittently, for as the liquid settles into the soil it drags air down after it. But when the liquid is allowed to stand upon the soil, and when, as it soaks gradually into the ground, fresh supplies of the liquid take its place, the ground soon becomes saturated, and the liquid, unpurified or but slightly improved, mixes with the subsoil-water and carries the contamination to a long distance. Even where wells are sunk to a great distance (one was sunk at Bondy, near Paris, to a depth of seventy-four meters, or two hundred and forty-seven feet), the surrounding soil is not free from danger of pollution by the soaking of the foul liquid into the sides of the well.

The localities from which specimens have been taken are designated somewhat at length in the tables. The stream referred to by Nos. 24 and 25, is the one alluded to in the previous report. It takes the drainage from several tanneries in Woburn, and empties into the Horn-pond outlet, a short distance below the end of the pond. My note of the condition of this stream, June 16, 1873, was as follows: —

TABLE VI. — *Examination of Mystic Lake, etc.* [Results expressed in parts per 100,000.]

| Number.         | DATE.                    | LOCALITY.                        | Ammonia. | "Albuminoid"<br>Ammonia. | SOLID RESIDUE OF FILTERED<br>WATER. |                             |        | Chlorine. | Phosphoric Acid. |
|-----------------|--------------------------|----------------------------------|----------|--------------------------|-------------------------------------|-----------------------------|--------|-----------|------------------|
|                 |                          |                                  |          |                          | Inorganic.                          | Organic<br>and<br>Volatile. | Total. |           |                  |
|                 |                          |                                  |          |                          |                                     |                             |        |           |                  |
| 19 <sup>1</sup> | 1873 — June 13 . . . . . | } Bacon's Bridge . . . . .       | 00.133   | 0.0280                   | 8.00                                | 2.85                        | 10.85  | 2.12      | . . .            |
| 20 <sup>2</sup> | " . . . . .              |                                  | 0.0136   | 0.0251                   | 9.00                                | 2.50                        | 11.50  | 2.00      | . . .            |
| 21 <sup>3</sup> | " . . . . .              |                                  | 0.0135   | 0.0216                   | 8.20                                | 1.30                        | 9.50   | 2.00      | . . .            |
| 22 <sup>4</sup> | " . . . . .              |                                  | 0.0133   | 0.0229                   | 8.50                                | 1.50                        | 10.00  | 1.96      | . . .            |
|                 |                          | Mean of 19, 20, 21, 22 . . . . . | 0.0134   | 0.0244                   | 8.42                                | 2.04                        | 10.46  | 2.02      | . . .            |
| 23 <sup>5</sup> | " 16 . . . . .           | Horn Pond outlet . . . . .       | 0.0076   | 0.0181                   | 4.90                                | 1.50                        | 6.40   | 1.24      | . . .            |
| 24 <sup>6</sup> | " . . . . .              | } Tannery Stream . . . . .       | 1.9120   | 0.1800                   | 52.50                               | 7.70                        | 60.20  | 23.60     | . . .            |
| 25 <sup>7</sup> | " . . . . .              |                                  | 1.7000   | 0.2000                   | 55.70                               | 5.00                        | 60.70  | 24.80     | 0.5116           |
| 26 <sup>8</sup> | " . . . . .              | } Abajonna River . . . . .       | 0.0266   | 0.0207                   | 8.60                                | 1.70                        | 10.20  | 1.45      | . . .            |
| 27 <sup>9</sup> | " . . . . .              |                                  | 0.0273   | 0.0241                   | 8.30                                | 1.50                        | 9.80   | 1.60      | . . .            |

1 Taken at middle of right-hand span. 1 foot below surface.

3 Taken at middle of right-hand span. 5 feet below surface.

5 Taken 1 foot below surface. Stream about 2½ feet deep.

Taken above Moseley's Tannery.

2 Taken at middle of right-hand span. 3½ feet below surface.

4 Taken at middle of left-hand span. 3½ feet below surface.

6 Taken at road-crossing.

7 Taken near outlet  
9 Taken below Moseley's Tannery. At northern culvert, under railroad.

TABLE VI.a. — *Examination of Mystic Lake, etc.* [Results expressed in Grains per U.S. Gallon.]

| Number. | DATE.          | LOCALITY.                    | Ammonia. | "Albuminoid."<br>Ammonia. | SOLID RESIDUE OF FILTERED<br>WATER. |                             |        | Chlorine. | Phosphoric Acid. |
|---------|----------------|------------------------------|----------|---------------------------|-------------------------------------|-----------------------------|--------|-----------|------------------|
|         |                |                              |          |                           | Inorganic.                          | Organic<br>and<br>Volatile. | Total. |           |                  |
| 19      | 1873 — June 13 | } Bacon's Bridge . . . . }   | 0.9078   | 0.0016                    | 4.67                                | 1.66                        | 6.33   | 1.24      | . .              |
| 20      | "              |                              | 0.0079   | 0.0015                    | 5.25                                | 0.46                        | 6.71   | 1.17      | . .              |
| 21      | "              |                              | 0.0079   | 0.0013                    | 4.79                                | 0.77                        | 5.55   | 1.17      | . .              |
| 22      | "              |                              | 0.0078   | 0.0013                    | 4.96                                | 0.88                        | 5.84   | 1.14      | . .              |
|         |                | Mean of 19, 20, 21, 22 . . . | 0.0079   | 0.0014                    | 4.92                                | 1.19                        | 6.11   | 1.18      | . .              |
| 23      | " 16           | Horn Pond outlet . . . .     | 0.0044   | 0.0011                    | 2.85                                | 0.88                        | 3.74   | 0.72      | . .              |
| 24      | "              | } Tannery Stream . . . }     | 1.1150   | 0.1050                    | 30.65                               | 4.49                        | 35.14  | 13.77     | . .              |
| 25      | "              |                              | 0.9920   | 0.1170                    | 32.51                               | 2.92                        | 35.43  | 14.47     | 0.299            |
| 26      | "              | } Abajonna River . . . }     | 0.0155   | 0.0120                    | 4.96                                | 0.99                        | 5.95   | 0.85      | . .              |
| 27      | "              |                              | 0.0159   | 0.0140                    | 4.84                                | 0.83                        | 5.72   | 0.93      | . .              |

"Tannery Stream crosses the road and runs through the fields into stream coming from Horn pond. Very filthy and black. When filtered the color of the liquid still blackish. No. 24 taken at road-crossing. No. 25 taken in the fields just beyond the crossing of the branch railroad running to the ice-houses. Rocks and banks covered with a black, filthy scum. Odor bad. (Dead animal a little below the place added to the odor.) The amount of water flowing was not very great; it would perhaps be equivalent to a stream eighteen inches wide by one and one-half deep\* flowing over a weir."

It is to be remarked, in this connection, that even if there were no animal refuse thrown into the Mystic tributaries, the water would still be contaminated by a greater or less proportion of vegetable organic matter coming from the copious growth of aquatic plants, which in summer covers the bed of the Winchester ponds and the banks of the Abajonna river.

#### THE MERRIMACK RIVER AS A SOURCE OF WATER-SUPPLY.

Of the cities on the Merrimack, Lowell is, at present, the only one which takes its water-supply from the river, although Lawrence will soon be supplied from that source; the works are now in process of erection. The character of the water has already been alluded to at some length. The suspended matter brought down by the river at certain seasons of the year renders it necessary that any scheme for using its water for domestic purposes should include some scheme for filtration. At Lowell it was at first proposed to accomplish the removal of the suspended matter, when found necessary, by means of filter-beds of sand, — a project which

\* This would amount to 0.24 cubic feet per second. The estimate, however, is but an approximation.



preliminary experiments showed to be feasible.\* This plan was subsequently changed for one involving a filtering gallery. This "filtering gallery is situated about 1,500 feet above Pawtucket bridge, in Dracut, on the northerly shore of the Merrimack river and parallel with it, about 100 feet from the water's edge. Its length is 1,300 feet, width eight feet and height (inside) eight feet. The top (inside) is level with the top of Pawtucket dam. The side-walls have an average thickness of two and three-fourths feet and a height of five feet, and are constructed of heavy rubble-masonry, laid water-tight in hydraulic mortar. The walls support a semi-circular brick arch, one foot thick, made water-tight. Along the bottom, stone braces, one foot square and eight feet long, are placed, ten feet from centre to centre between the walls, to keep them in position. The bottom is covered with coarse-screened gravel, one foot thick, to the level of the brace-stones. The depth of the excavation averaged about sixteen feet, which carried it down into the natural gravel bed." †

At the lower extremity of the filtering gallery is situated the inlet-chamber, from which starts the supply-conduit, and into which the water from the river may be admitted by a direct pipe. "The filtering gallery was not intended to be used as the principal source of supply, but only during times of freshet, when the river contains a considerable amount of matter in suspension. When the water is clear, it is to be taken from the river through the inlet-pipe." From the inlet-chamber a *supply-conduit*, four feet three inches in diameter and 4,183 feet in length, conducts the water to the terminal chamber, whence a 30-inch cast-iron pipe, 6,656 feet in length, extends to the engine-house. From the

\* See the Report of the Joint Special Committee on a Supply of Water for the City of Lowell, September, 1869.

† Third Annual Report of the Water Commissioners of the City of Lowell, January, 1873.

engine-house to the reservoir the distance is 2,666 feet, making the entire distance from the end of the filtering-gallery to the reservoir 13,505 feet.

Although the filtering-gallery was, according to the report quoted above, intended for use only when the river was rendered sufficiently turbid to be objectionable, up to the present time (December, 1873), no water has been taken directly from the river since the last week in July, when the engine was tested. As soon as the test was ended the river-gate was closed, and has remained closed ever since. The amount of water pumped during this time has been as follows\* : —

|                        |   |   |                     |
|------------------------|---|---|---------------------|
| August (from the 12th) | . | . | 11,906,518 gallons. |
| September              | . | . | 22,111,990 “        |
| October                | . | . | 14,060,740 “        |
| November               | . | . | 9,932,230 “         |
| December               | . | . | 21,366,130 “        |

The theory on which this system of drawing a supply of water from the river is based is, that the water from the river which percolates the earthy or gravelly barrier between it and the gallery shall, deprived of its suspended matter, rise through the porous bottom of the gallery. “Bordering upon all rivers there are found, at intervals, narrow plains of gravel or sand, brought down and deposited there by the river under the varying positions of its channel-way. When these beds of gravel extend to a depth below the bottom of the neighboring stream, they will always be found saturated with water, mainly derived from that stream, and, however turbid the water of the river, this underground flow will always be found clear, provided that we tap it at a reasonable distance from the

\* For information on this and other points connected with the water-supply of Lowell, I am indebted to Mr. George E. Evans, Chief Engineer of the Water Works.

channel-way.\* Several cities in Europe are supplied with water by covered galleries carried through these beds of gravel; and a few other cities besides Lowell, on this continent, are supplied, or to be supplied, in this way.

"In many cases these galleries are technically called filtering-galleries; but, in reality, they are mere receptacles and conduits for gathering water already filtered by a natural process. They serve nothing towards the filtration of the water, but only towards the collection of it and its transmission to the pumping-machines." (Kirkwood, *Filtration of River Waters*, p. 139.)

The filtering-gallery at Lowell is of this character, and although some of the water collected in it comes from the river directly, a large portion comes no doubt from the land side, and the underground water on its way to the river is thus intercepted. It was found that in the trial-wells sunk before the construction of the filtering-gallery was determined upon, the water stood somewhat higher in the well than in the river; that its temperature was very uniform, being in summer very much colder than that of the river, and that it was also harder.†

Facts have been observed in connection with the filtering-gallery, also, which lead to similar conclusions, and which will be described in some detail. In the first place, the chemical examinations seem to show too great a difference between the character of the water in the gallery and that of the river-water to be accounted for by filtration through a

\* Report on the Filtration of River Water for the Supply of Cities, as practised in Europe, made to the Board of Water Commissioners of the City of St. Louis, by James P. Kirkwood, Civil Engineer. New York, Van Nostrand, 1869, p. 17.

† Mr. Kirkwood, in the report referred to above, speaks of the gallery-water at Lyons as containing a larger proportion of salts of lime than the river-water (see p. 137). It is a matter of regret that this standard report on the subject of filtration does not contain results of chemical examination.

TABLE VII. — *Examination of Filtering Scheme at Lowell.* [Results expressed in Parts per 100,000.]

| Number.          | DATE.        | LOCALITY.                                              | Ammonia. | "Albuminoid"<br>Ammonia. | SOLID RESIDUE OF FIL-<br>TERED WATER. |                             |                   | Sulphuric Acid<br>(SO <sub>3</sub> ). | Silica (SiO <sub>2</sub> ). | Alumina and<br>Oxide of Iron. | Lime. | Magnesia. |
|------------------|--------------|--------------------------------------------------------|----------|--------------------------|---------------------------------------|-----------------------------|-------------------|---------------------------------------|-----------------------------|-------------------------------|-------|-----------|
|                  |              |                                                        |          |                          | Inor-<br>ganic.                       | Organic<br>and<br>Volatile. | Total.            |                                       |                             |                               |       |           |
| 101 <sup>1</sup> | 1873—Sept. 2 | { Merrimack River, opposite<br>inlet chamber . . . . . | 0.0047   | 0.0153                   | 1.76                                  | 2.32                        | 4.08 <sup>2</sup> | . .                                   | . .                         | . .                           | . .   | . .       |
| 120 <sup>1</sup> | " 10         |                                                        | 0.0047   | 0.0104                   | 1.56                                  | 1.44                        | 3.00              | 0.34                                  | 0.50                        | 0.30 <sup>3</sup>             | 0.55  | trace.    |
| 121 <sup>4</sup> | " 10         |                                                        | 0.0044   | 0.0100                   | 1.80                                  | 1.84                        | 3.64              | . .                                   | . .                         | . .                           | . .   | . .       |
| 207 <sup>5</sup> | 1874—Jan. 1  |                                                        | 0.0053   | 0.0100                   | 2.48                                  | 2.00                        | 4.48              | . .                                   | . .                         | . .                           | . .   | . .       |
| 102              | 1873—Sept. 2 | { Inlet chamber . . . . .                              | 0.0013   | 0.0027                   | 4.84                                  | 1.80                        | 6.64              | . .                                   | 0.40                        | 0.20                          | 0.86  | trace.    |
| 119              | " 10         |                                                        | 0.0013   | 0.0020                   | 4.64                                  | 1.16                        | 5.80              | . .                                   | 0.38                        | 0.14                          | 0.93  | trace.    |
| 105              | 1874—Jan. 2  |                                                        | 0.0063   | 0.0037                   | 5.20                                  | 1.20                        | 6.40              | . .                                   | . .                         | . .                           | . .   | . .       |
| 103              | 1873—Sept. 2 |                                                        | 0.0020   | 0.0057                   | 5.64                                  | 1.44                        | 7.08              | . .                                   | . .                         | . .                           | . .   | . .       |
| 74               | July 10      | { Engine House . . . . .<br>Water as delivered in {    | 0.0020   | 0.0057                   | 5.24                                  | 1.48                        | 6.72              | . .                                   | . .                         | . .                           | . .   | . .       |
| 206              | 1874—Jan. 2  |                                                        | 0.0037   | 0.0034                   | 6.28                                  | 1.24                        | 7.52              | . .                                   | . .                         | . .                           | . .   | . .       |

<sup>1</sup> Taken 100 feet from shore, 1½ feet below surface.<sup>3</sup> Trace of phosphoric acid.<sup>2</sup> The unfiltered water contained — inorganic, 2.00; organic, 2.40; total, 4.40.  
<sup>4</sup> Taken 100 feet from shore.      <sup>5</sup> Taken 100 feet from shore, 7 feet below surface.

TABLE VII. a. — *Examination of Filtering Scheme at Lowell.* [Results expressed in Grains per U. S. Gallons.]

| Number.          | DATE.          | LOCALITY.                                             | Ammonia. | "Albuminoid"<br>Ammonia. | SOLID RESIDUE OF FIL-<br>TERED WATER. |                             |                   | Chlorine. | Sulphuric Acid<br>(SO <sub>3</sub> ). | Silica (SiO <sub>2</sub> ). | Alumina and<br>Oxide of Iron. | Lime. | Magnesia. |
|------------------|----------------|-------------------------------------------------------|----------|--------------------------|---------------------------------------|-----------------------------|-------------------|-----------|---------------------------------------|-----------------------------|-------------------------------|-------|-----------|
|                  |                |                                                       |          |                          | Inor-<br>ganic.                       | Organic<br>and<br>Volatile. | Total.            |           |                                       |                             |                               |       |           |
| 101 <sup>1</sup> | 1873 — Sept. 2 | {<br>Merrimack River, oppo-<br>site inlet-chamber . . | 0.0027   | 0.0089                   | 1.03                                  | 1.35                        | 2.38 <sup>2</sup> | 0.08      | . .                                   | . .                         | . .                           | . .   | . .       |
| 120 <sup>1</sup> | " 10           |                                                       | 0.0027   | 0.0060                   | 0.91                                  | 0.84                        | 1.75              | 0.06      | 0.20                                  | 0.29                        | 0.18 <sup>3</sup>             | 0.32  | trace.    |
| 121 <sup>4</sup> | " 10           |                                                       | 0.0026   | 0.0058                   | 1.05                                  | 1.07                        | 2.12              | 0.07      | . .                                   | . .                         | . .                           | . .   | . .       |
| 207 <sup>5</sup> | 1874 — Jan. 1  |                                                       | 0.0031   | 0.0058                   | 1.45                                  | 1.17                        | 2.62              | 0.12      | . .                                   | . .                         | . .                           | . .   | . .       |
| 102              | 1873 — Sept. 2 | {<br>Inlet-chamber . . . . .                          | 0.0008   | 0.0016                   | 2.82                                  | 1.05                        | 3.87              | 0.14      | . .                                   | 0.23                        | 0.12                          | 0.50  | trace.    |
| 119              | " 10           |                                                       | 0.0008   | 0.0012                   | 2.71                                  | 0.68                        | 3.39              | 0.12      | 0.16                                  | 0.57                        | 0.08                          | 0.57  | trace.    |
| 205              | 1874 — Jan. 2  |                                                       | 0.0038   | 0.0022                   | 3.04                                  | 0.70                        | 3.74              | 0.15      | . .                                   | . .                         | . .                           | . .   | . .       |
| 103              | 1873 — Sept. 2 | Engine House . . . . .                                | 0.0012   | 0.0033                   | 3.29                                  | 0.84                        | 4.13              | 0.22      | . .                                   | . .                         | . .                           | . .   | . .       |
| 74               | July 10        | Water as delivered in                                 | 0.0012   | 0.0039                   | 3.06                                  | 0.86                        | 3.92              | 0.18      | . .                                   | . .                         | . .                           | . .   | . .       |
| 206              | 1874 — Jan. 2  | Lowell . . . . .                                      | 0.0022   | 0.0020                   | 3.67                                  | 0.72                        | 4.39              | 0.18      | . .                                   | . .                         | . .                           | . .   | . .       |

1 Taken 100 feet from shore. 1½ feet below surface.

2 The unfiltered water contained — inorganic, 1.17; organic, 1.40; total, 2.57.

3 Trace of phosphoric acid.

4 Taken 100 feet from shore. 6 feet below surface.

5 Taken 100 feet from shore. 7 feet below surface.



hundred feet or less of gravel. A comparison between the water of the river and that of the gallery may be made by observing the results of the examinations recorded in Tables VII. and VII.a. The samples numbered 205, 206, 207 were kindly procured for me by Mr. George E. Evans, Chief Engineer of the Water Works.

It will be observed that the total solid residue is larger and that the proportion of mineral matter is also larger within the gallery than in the river opposite to it. It will be observed also that the gallery-water contains a smaller proportion of nitrogenous organic matter as indicated by the "albuminoid ammonia." That the water, as delivered in Lowell, should differ somewhat from that in the gallery (compare Nos. 205 and 206) is not a matter of surprise, for the conduit which conveys the water from the gallery to the city is for a portion of the distance a tunnel cut through a hill of schist rock. The rock inside the hill has a tolerably well-marked dip of about  $45^{\circ}$  towards the north. The tunnel runs on the strike of the rock and consequently cuts the minimum number of lines of bedding; still some water does enter the tunnel along these lines, and also, though to a less extent, through the joints of the rock which have the same strike, but have a dip which is at right angles to that of the beds.

Another point of observed difference between the river-water and the water of the gallery is the relative proportion of the gases held in solution by the water. Thus, on September 10th, 1873, the water in the river opposite the gallery, at a temperature of  $20^{\circ}$  C. ( $68^{\circ}$  F.), was found to contain 1.84 cubic centimeters of oxygen to the liter (*0.43* of a cubic inch to the gallon) while that in the gallery, the temperature of which was  $9.75^{\circ}$  C. ( $50^{\circ}$  F.), contained only 0.7 of a cubic centimeter (*0.16* of a cubic inch to the gallon \*).

\* Some of the same water was examined in the laboratory after being brought to Boston, and found to contain: —

Determinations of the amount of oxygen in solution were also made in the laboratory, in the case of Nos. 205, 206, and 227, as follows:—

| Number. | DATE.        | LOCALITY.                          | Cubic Centimeters of Oxygen to the Liter. | Cubic Inches of Oxygen to the Gallon. |
|---------|--------------|------------------------------------|-------------------------------------------|---------------------------------------|
| 207     | Jan. 1, 1874 | River . . . . .                    | 7.90                                      | 1.82                                  |
| 205     | 2, 1874      | Inlet-chamber . . . . .            | 2.75                                      | 0.64                                  |
| 206     | 2, 1874      | Water as drawn in Lowell . . . . . | 7.45                                      | 1.72                                  |

The temperature of these samples *at the time of examination* was: No. 207, 8.5° C. (47.3° F.); No. 205, 7.25° C. (45° F.); No. 206, 6.75° C. (44° F.).

From these last determinations it would seem that, in the passage from the inlet-chamber to the reservoir, and during the exposure in the reservoir, the water takes up oxygen to about the same amount as exists in the river-water. It

|                                               | CUBIC CENTIMETERS PER LITER. |                | CUBIC INCHES PER GALLON. |                |
|-----------------------------------------------|------------------------------|----------------|--------------------------|----------------|
|                                               | River-water.                 | Gallery-water. | River-water.             | Gallery-water. |
| Oxygen . . . . .                              | 1.904                        | 1.015          | <b>0.440</b>             | <b>0.234</b>   |
| Carbonic Acid . . . .                         | 8.101                        | 9.238          | <b>1.871</b>             | <b>2.134</b>   |
| Nitrogen . . . . .                            | 7.339                        | 7.424          | <b>1.695</b>             | <b>1.715</b>   |
| Total . . . . .                               | 17.344                       | 17.677         | <b>4.006</b>             | <b>4.083</b>   |
| Per cent. of oxygen }<br>in the mixed gases } | 10.91                        | 5.74           | ..                       | ..             |

It is to be remarked that the amount of oxygen in the gallery-water was thus found to be greater than in the case of the determinations made on the spot, which is accounted for by the fact that a water so deficient in oxygen readily absorbs more of this gas when exposed even for a short time to the air.

appears further, that during the winter the river-water itself contains much more oxygen than during the summer.

Another point of difference between the water of the river and that in the gallery is, that while the water in the river varies very much in temperature from winter to summer, the temperature of the water in the gallery is almost constant. No record has been kept of the temperature in the gallery itself, but observations have been regularly made in the well of the engine-house, which is essentially the same thing. During the month of September the highest temperature was  $50^{\circ}$  F., the lowest  $49^{\circ}$  F.; during the entire month of October, observations made on thirteen different days showed identically the same temperature, namely,  $50^{\circ}$  F. Between September 6 and January 1, the highest recorded observation is  $52^{\circ}$  F., on November 8, and the lowest is  $47^{\circ}$  F., December 31, A. M. I have no corresponding record of the temperature of the river, nor is such necessary, as every one knows that river-water varies with the temperature of the surrounding air. The average temperature of the water in the reservoir has been :—

|           |   |   |   |   |                    |
|-----------|---|---|---|---|--------------------|
| In August | . | . | . | . | $73.22^{\circ}$ F. |
| September | . | . | . | . | $65.05^{\circ}$ F. |
| October   | . | . | . | . | $58.27^{\circ}$ F. |
| November  | . | . | . | . | $42.89^{\circ}$ F. |
| December  | . | . | . | . | $40.09^{\circ}$ F. |

It would seem difficult to account for this very great uniformity of the temperature of the water of the filtering-gallery on the supposition that the water is mainly derived from the river and simply filters through 100 feet or so of gravel.

It has been said that, in the trial well, the water in the gallery stood above the level of that in the river. I do not find this to be the case in the gallery. A record is kept of the height of water, not in the gallery itself, but in the well

of the engine-house. Early in the day, before the pumping begins, this height may be taken as sensibly the same as that in the gallery.

It may be interesting to compare the height, at various dates, of the water in the gallery and in the river.

| DATE.             | HEIGHT ABOVE OR BELOW TOP OF DAM. |                      |             |
|-------------------|-----------------------------------|----------------------|-------------|
|                   | Of Water in River.                | Of Water in Gallery. | Difference. |
| Sept. 2 . . . . . | 2 ft.      above.                 | 0 ft. 6 in. below.   | 2 ft. 6 in. |
| 11 . . . . .      | 1    11 in.    "                  | 1    7      "        | 3    6      |
| Oct. 11 . . . . . | 3    0      "                     | 0    2      "        | 3    8      |
| 22 . . . . .      | 5    10      "                    | 0    6      "        | 6    4      |
| Dec. 3 . . . . .  | 2    4      "                     | 0    0      "        | 2    4      |
| 31 . . . . .      | 2    3      "                     | 0    0      "        | 2    3      |

The highest point at which the water has stood was on a level with the top of the dam; this point is recorded as having been reached only twice,—in both cases after an interval of nearly a week had elapsed since the pumps had been in operation. The highest point which the river reached during the interval over which comparative observations have extended (August 13 to January 1) was five feet ten inches; this was on October 22.

As far as the quality of the water goes, chemical examination points to no objection that can be urged against it; for although it is sufficiently aerated in the gallery, it seems, in the reservoir, to become as highly charged with atmospheric gases as the water of the river. The amount of organic matter is very small, the amount of mineral matter is not excessive, and it seems that, with the present demand upon it, the filtering-gallery furnishes water suitable in every way for domestic use.

*Lawrence.*—At Lawrence the proposed water-works are now



in process of construction, on a plan somewhat similar to that adopted in Lowell. In the experiments made to determine the best locality for a filtering-gallery, a well was sunk through sand, with some thin strata of clay, into a bed of coarse, clean gravel. The well was sunk to a depth of about eight feet below the river-surface, or five feet below the top of the Essex Company's dam. Two steam-pumps, whose united capacity exceeded 300 gallons per minute, working constantly night and day, were just able to keep the surface of the water in the well about seven and one-fourth feet below that of the river. With such a draught upon the well, whose water-surface was about thirty-seven square feet, a large proportion of the incoming water must have been derived from the river; the water which came into the well was perfectly clear and transparent, and in taste and quality was all that could be desired.

"The whole river-bank being composed of sand and gravel, with very little material that would hinder the free passage of the water, the well was free to draw, not only from the river by direct filtration, but also from all the surrounding earth, which might be looked upon as an immense subterranean storage reservoir. That this was actually the case there are numerous indications. The amount of water delivered by the well gradually decreased as the pumping continued, — the rate of flow, after three weeks' pumping, not being one-half of that it was at first. The temperature of the water of the river at Lawrence was about 60 degrees, but the well-water was about 50 degrees, thus indicating that a large proportion of the water came from the earth, where the temperature remains quite constant through the various seasons, instead of from the river. The analyses of Dr. Hasenclever indicate the same thing in a different way, — samples of the water taken from the river showing 0.7 degrees of hardness, while those of the well showed 2.5 degrees." \*

\* See Report on Proposed Water-Works, Lawrence, City Document, 1872.



In the scheme for the city supply, it is proposed to draw directly from the river, except when the river is turbid.

In these schemes for filtration, it is to be borne in mind that the filtering-galleries or basins are, in a measure, also shallow wells, and the subsoil, from which they derive in part their supply, must be carefully protected from impurities which would be brought from cesspools and vaults, and from drains.

It seems, as has already been said, that at the present time the water thus obtained is perfectly satisfactory in quality, and in reality superior to the river, not only on account of its quite uniform and low temperature, but also because of its containing a smaller amount of organic matter, and because the liability of contamination, if proper precautions be taken, is probably less. As to the permanence of the supply, there seems to be no cause for anxiety, although the amount of water which can be obtained is not unlimited. If the amount pumped from the gallery is so great as to cause a drain upon that portion of the supply which comes from the land side, it is probable that the water thus derived would be somewhat inferior, and that more than the ordinary proportion would be drawn from the river. In such case, in times when the river is very turbid, the water might fail to be filtered satisfactorily. It is not likely that any difficulty will arise from the silting up of the bed of the river, as it is sandy or gravelly in its character, and the freshets probably exercise enough of a scouring action to keep it clean.

#### CHARLES RIVER AS A SOURCE OF WATER-SUPPLY.

For many years Charles river has been looked to by various municipalities as affording a possible supply of water for domestic use, and the controversy between those who favored Charles river and those who favored Long pond (Cochituate) was, at the time of the proposed introduction of aqueduct-water into Boston, quite bitter, and gave rise to a host of

pamphlets and newspaper articles. The introduction of water from this source into Dedham, West Roxbury, Brookline, Newton, Waltham, and Watertown has been proposed at various times since, but Waltham is at present the only town supplied.

The water of the river, as far as chemical examination can show (that is, in the upper part of its course), is at present quite well suited for domestic and manufacturing use, with the exception that, in some cases, the vegetable coloring-matter is objectionable, — interfering, for instance, with its use in connection with bleaching processes. Although, on account of the nature of the bed of the river and the soil through which it flows, the Charles is inferior to a river like the Merrimack, the great objection to be urged against its use as a source of supply is the danger to which it is liable, of being made very soon the carrier of sewage from the growing towns upon its banks. The use of the water by the towns on the upper part of the stream, and the return of water to the river as sewage, could not fail to have an unfavorable effect upon its quality for use by the towns situated lower down on the stream, and such statements as the following, which appears in the Waltham Water Report (1872), are to be regarded as depreciating, although perhaps unintentionally, a matter which is really of great importance: "The question of sewage is not at present of immediate importance to us [inhabitants of Waltham] in its effect upon the quality of the water; undoubtedly, in time, as population increases upon its banks, some comprehensive system will have to be adopted; in a growing country like ours, we cannot provide for too great a distance in the future."

Waltham derives its water-supply in theory from Charles river, but the water is not taken from the river directly. Use, in this case, is made of what is called a filter-basin. This basin was constructed at the side of the stream, partly by making an excavation into the knoll, at the foot of which the

basin is situated, and partly, on three sides in fact, by inclosing a portion of the river by a gravel embankment some thirty or forty feet wide. This embankment slopes outward on the river-side, but is walled perpendicularly on the side towards the basin. The idea at first was, that the river-water should *filter through* this gravel embankment, and the filtered-water should then be pumped into the reservoir and distributed for domestic use. Practically, it seems, however, that the basin draws the main part of its supply, not from the river, but from springs, — from the underground flow towards the river. Various circumstances point to this conclusion. In the first place it was noticed, before the construction of the basin, that in winter there was generally open water at this point in the river, or when ice did form in extreme cold weather, that it was thinner than on the river itself, indicating the entrance of warmer water from the land. Further, during the construction of the basin it was found that water came into it so rapidly from springs, that it was necessary to pump at the rate of 4,000 gallons per minute in order to remove the water that the work might go on; moreover, the water sometimes stands higher in the basin than in the river, and the temperature is quite uniformly  $49^{\circ}$  or  $50^{\circ}$  F. The pumps are now working from six to twelve hours per day, Sunday excepted. On Monday morning, when the weather is cold, the water — which had then stood in the basin some thirty-six hours — is found to be skimmed over with ice, having acquired at the surface a low temperature; but, during the week, as the water is constantly renewed and constantly supplied, it is found that the temperature varies but slightly.

Chemical examination of water from the river and from the basin also leads to the same conclusion, — the water of the basin being harder, and containing less organic matter, as we should expect, if the water indeed comes in considerable measure from the underground flow. The water for examination was obtained through the kindness of Dr. R. S. War-

ren, of Waltham, who attended personally to its collection, and the results of the chemical examination are incorporated in Tables VIII. and VIII.a.

From the filter-basin the water is pumped through a cast-iron pipe, 2,950 feet long, into a reservoir situated at an elevation of some 130 feet above the main street; from this reservoir it is distributed through cement-lined pipes.

#### NOTE.

Since this Report was presented to the Board of Health, I have made a further comparison of the water in the filter-basin at Waltham, and that in the river, by determining the amount of oxygen held in solution in each case. The determinations were made on the morning of Saturday, February 7, 1874, on the spot. The temperature of the air at the outer portion of the filter-basin and on the river was  $-7^{\circ}$  C. ( $19.4^{\circ}$  F.); at the inner portion of the filter-basin under the shelter of the engine-house, the temperature was about  $-3^{\circ}$  C. ( $26.6^{\circ}$  F.), and while the river was completely frozen over the filter-basin was entirely free from ice.

The specimens examined were as follows:—

No. 213, from the river some ten feet from the embankment, taken six feet below the surface.

No. 214, from the river at the surface just under the ice.

No. 215, from that side of the filter-basin nearest the river, taken just below the surface.

No. 216, from that side of the filter-basin nearest the engine-house, taken from the bottom.

No. 217, from the faucet in the house of the engineer. This house is situated on the hill above the engine-house, and is supplied by a pipe from the force-main, not from the reservoir.

The results of the examination are as follows:—

TABLE VIII. — *Examination of Filtering Scheme at Waltham.* [Results expressed in Parts per 100,000.]

| Number.          | DATE.          | LOCALITY.                     | Ammonia. | "Albuminoid"<br>"Ammonia." | SOLID RESIDUE OF FIL-<br>TERED WATER. |                             |        | Chlorine. | Sulphuric Acid<br>(SO <sub>3</sub> ). | Silica (SiO <sub>2</sub> ). | Alumina and<br>Oxide of Iron. | Lime. | Magnesia.         |
|------------------|----------------|-------------------------------|----------|----------------------------|---------------------------------------|-----------------------------|--------|-----------|---------------------------------------|-----------------------------|-------------------------------|-------|-------------------|
|                  |                |                               |          |                            | Inor-<br>ganic.                       | Organic<br>and<br>Volatile. | Total. |           |                                       |                             |                               |       |                   |
| 187              | 1873 — Dec. 16 | Charles River, at Waltham . . | 0.0060   | 0.0164                     | 3.88                                  | 1.84                        | 5.72   | 0.40      | 0.89                                  | 0.57                        | 0.19                          | 0.71  | 0.02              |
| 192              | Nov. 18        | } Filter Basin . . . . . {    | 0.0013   | 0.0033                     | 5.20                                  | 1.20                        | 6.40   | 0.44      | 1.50                                  | 0.75                        | 0.28                          | 1.59  | trace.            |
| 194 <sup>1</sup> | Dec. 16        |                               | 0.0047   | 0.0056                     | 5.60                                  | 0.92                        | 6.52   | 0.38      | 0.84                                  | 1.03                        | 0.03                          | 1.63  | 0.17 <sup>1</sup> |
| 195              | " 16           | Reservoir . . . . .           | 0.0049   | 0.0049                     | 5.52                                  | 0.88                        | 6.40   | 0.36      | 2                                     | 2                           | 2                             | 2     | 2                 |
| 193              | Nov. 17        | } House of Dr. Warren . . . { | 0.0060   | 0.0070                     | 7.48                                  | 0.92                        | 8.40   | 0.42      | 2                                     | 2                           | 2                             | 2     | 2                 |
| 196              | Dec. 16        |                               | 0.0020   | 0.0013                     | 5.56                                  | 0.96                        | 6.52   | 0.34      | 2                                     | 2                           | 2                             | 2     | 2                 |

<sup>1</sup> The results in the last five columns opposite No. 194, were obtained from a mixture of equal parts of Nos. 196, 195, 194.<sup>2</sup> See the preceding note, and No. 194 above.



TABLE VIIIa. — *Examination of Filtering Scheme at Waltham.* [Results expressed in Grains per U. S. Gallon.]

| Number.          | DATE.          | LOCALITY.                | Ammonia. | "Albaminoid"<br>Ammonia. | SOLID RESIDUE OF FILTERED<br>WATER. |                              |        | Chlorine. | Sulphuric Acid<br>(SO <sub>3</sub> ) | Silica (SiO <sub>2</sub> ) | Alumina and Ox-<br>ide of Iron. | Lime. | Magnesia.         |
|------------------|----------------|--------------------------|----------|--------------------------|-------------------------------------|------------------------------|--------|-----------|--------------------------------------|----------------------------|---------------------------------|-------|-------------------|
|                  |                |                          |          |                          | Inorganic.                          | (Organic<br>and<br>Volatile. | Total. |           |                                      |                            |                                 |       |                   |
| 197              | 1873 — Dec. 16 | Charles Riv., at Waltham | 0.0035   | 0.0066                   | 2.23                                | 1.07                         | 3.33   | 0.23      | 0.52                                 | 0.33                       | 0.11                            | 0.41  | rac               |
| 192              | Nov. 18        | { Filter-basin . . . }   | 0.0008   | 0.0019                   | 3.04                                | 0.70                         | 3.74   | 0.26      | 0.88                                 | 0.44                       | 0.16                            | 0.93  | trace             |
| 149 <sup>1</sup> | Dec. 16        |                          | 0.0027   | 0.0033                   | 3.27                                | 0.54                         | 3.81   | 0.22      | 0.49                                 | 0.16                       | trace.                          | 0.95  | 0.10 <sup>1</sup> |
| 195              | " 16           | Reservoir . . . . .      | 0.0029   | 0.0029                   | 3.23                                | 0.51                         | 3.74   | 0.21      | 2                                    | 2                          | 2                               | 2     | 2                 |
| 193              | Nov. 17        | { House Dr. Warren }     | 0.0035   | 0.0041                   | 4.33                                | 0.54                         | 4.90   | 0.25      | ..                                   | ..                         | ..                              | ..    | ..                |
| 196              | Dec. 17        |                          | 0.0042   | 0.0007                   | 3.24                                | 0.56                         | 3.80   | 0.20      | 2                                    | 2                          | 2                               | 2     | 2                 |

<sup>1</sup> The results in the last five columns opposite No. 194 were obtained from a mixture of equal parts of Nos. 196, 195, 194.

<sup>2</sup> See the preceding note and No. 194 above.

| Number. | LOCALITY.                            | Temperature in Centigrade degrees. | Oxygen in cubic centimeters per liter. | Temperature in Fahrenheit degrees. | Oxygen in cubic inches to the gallon. |
|---------|--------------------------------------|------------------------------------|----------------------------------------|------------------------------------|---------------------------------------|
| 213     | River 6 feet below surface . . . . . | 0.5°                               | 13.07                                  | 32.9°                              | 3.02                                  |
| 214     | River, surface . . . . .             | 0.°                                | 13.20                                  | 32.°                               | 3.05                                  |
| 215     | Filter basin . . . . .               | 6.5°                               | 8.71                                   | 43.7°                              | 2.01                                  |
| 216     | " . . . . .                          | 7.°                                | 8.71                                   | 44.6°                              | 2.01                                  |
| 217     | Dwelling-house . . . . .             | 2.5°                               | 10.02                                  | 36.5°                              | 2.31                                  |

In connection with the facts already mentioned, these results would seem to confirm the idea that the water comes in considerable measure from springs. This *comparative deficiency* in oxygen cannot be offered as an objection to the use of the water for drinking, as the *absolute amount* is not small, and by exposure in the reservoir it, no doubt, absorbs oxygen. Even just after it enters the force-main we see (No. 217) it is found already to contain rather more than in the basin. Moreover, a sample of water taken from the filter-basin in a (clean) wooden pail, the water being somewhat agitated by the operation, after being exposed to the air a short time, was found to contain 9.58 c.c. to the liter (2.21 cubic inches to the gallon.) That in respect to the dissolved oxygen there should not be as marked a difference as was observed at Lowell, is not strange, when we consider the large surface which the Waltham basin exposes to the air. It is possible, also, that determinations made later in the day — after the water which had remained in the basin for some time had been pumped out — would have shown a greater difference. It is proposed to make further examinations with reference to this matter.

## APPENDIX A.

## METHODS OF ANALYSIS.

*Collection of Samples.* — The water was collected in glass-stoppered bottles which have never been used except for this purpose. The water was taken, as a rule, at the depth of eighteen inches below the surface, and the bottles were thoroughly rinsed with the water to be collected before being finally filled.

*Suspended Matters.* — Various methods are in use for determining the amount of matter in suspension. None of them are perfectly free from objection. If there is considerable suspended matter, it may be collected on a tared filter and weighed; this method is, however, quite inaccurate where small quantities are in question. The method of allowing the water to stand for some days or weeks, and then collecting the sediment, is open to the very serious objection that even in the case of tolerably pure waters the chemical changes which immediately begin to take place alter very decidedly the amount and character of the suspended matters, — an effect which is much more marked in the case of waters rendered impure by admixture with sewage or manufacturing refuse. The following method, as affording greater accuracy, has therefore been followed: — A portion of the water, well shaken up (100 or 250 c.c. according to its quality), is evaporated to dryness, and the weight of the residue determined; a quantity of the original water is then filtered through the best filter-paper, that which filters through at first being rejected, until the filter has been thoroughly washed with the water under examination. A portion of the water thus filtered is

evaporated to dryness, and the difference between the results obtained in the two cases may with sufficient accuracy be taken as the "suspended matter." In the foregoing tables the results of the analytical determinations are given just as obtained, and the suspended matter is not tabulated as such. When the amount of suspended matter was not large enough to estimate, the water was still passed through a filter in order that the results might be directly comparable with each other.

*Solid Residue.* — The amount of water taken for the determination of the solid residue was 100 c.c. or 250 c.c. according to the purity of the water. The evaporation of larger quantities tends to inaccuracy, as the operation is of necessity more prolonged, and in many cases the organic matter undergoes chemical change when subjected for a long time to the temperature of boiling-water. The residue was dried at 100° C. (212° F.) and weighed. It was then ignited at as low a temperature as possible, was treated with distilled water saturated with carbonic acid, and dried again at 100 degrees. The difference between the two weights appears in the tables as organic and volatile matter.

This determination of organic matter is sufficiently accurate for practical purposes, except when the water contains a considerable amount of nitrates and chlorides.

*Chlorine.* — The chlorine was determined volumetrically by means of a standard solution of nitrate of silver.

*Ammonia and Albuminoid Ammonia.* — The method of water analysis proposed by Messrs. Wanklyn, Chapman and Smith, of determining the amount of ammonia by distillation with carbonate of soda, and subsequently heating with a strongly alkaline solution of permanganate of potassium has been followed as affording the best and most available means at present at our command for obtaining indications of the amount of the nitrogenous organic matter in solution.

*Oxygen.* — The oxygen dissolved in the waters has been

determined in several instances, — generally by the use of a titrated solution of hydrosulphite of sodium, as suggested by Schützenberger and Risler (see Bulletin de la Société Chimique, XX., 1873, p. 145.) This method supplies a want long felt, of some ready and convenient means of determined free oxygen, and the operation can be performed without difficulty in the open air, as, for instance, in a row-boat or in other similar situations. For the determinations made during the summer, I am indebted to Mr. T. E. Pope. As, at that time, the complete details of Schützenberger's process, as finally adopted, had not been made public, we employed a method in some points modified from that originally suggested. To test the accuracy of the method employed, the following determinations were made, in which the results were compared with those obtained from the same water, by the ordinary method of analyzing the gases dissolved by water (a Sprengel's mercury pump was used) : —

No. 105. Charles river water collected at Needham on September 5, was examined the same day, and found to contain—

|                | By gas analysis. | By titration. |                                   |
|----------------|------------------|---------------|-----------------------------------|
| Nitrogen . . . | 9.10             | —             | } Cubic centimeters<br>per liter. |
| Oxygen . . .   | 2.84             | 2.89          |                                   |

No. 106. Charles river, Newton Upper Falls. The water was collected on September 5, and examined on the following day. The results were —

|                | By gas analysis. | By titration. |                                   |
|----------------|------------------|---------------|-----------------------------------|
| Nitrogen . . . | 8.08             | —             | } Cubic centimeters<br>per liter. |
| Oxygen . . .   | 2.95             | 3.00          |                                   |

No. 107. Nearly same locality as No. 106.



|                | By gas analysis. | By titration. |                                   |
|----------------|------------------|---------------|-----------------------------------|
| Nitrogen . . . | 7.678            | —             | } Cubic centimeters<br>per liter. |
| Oxygen . . .   | 2.732            | 2.74          |                                   |

No. 119. Inlet-chamber of filtering-gallery, Lowell, Mass. Collected September 10, examination made in the laboratory September 11.

|                   | By gas analysis. | By titration. |                                   |
|-------------------|------------------|---------------|-----------------------------------|
| Nitrogen . . .    | 7.424            | —             | } Cubic centimeters<br>per liter. |
| Oxygen . . .      | 1.015            | 1.02          |                                   |
| Carbonic acid . . | 9.238            | —             |                                   |

No. 121. Merrimack river, Lowell, opposite inlet-chamber of filtering-gallery. Collected September 10, examined September 11.

|                   | By gas analysis. | By titration. |                                   |
|-------------------|------------------|---------------|-----------------------------------|
| Nitrogen . . .    | 7.339            | —             | } Cubic centimeters<br>per liter. |
| Oxygen . . .      | 1.904            | 1.85          |                                   |
| Carbonic acid . . | 8.101            | —             |                                   |

The determinations recorded in December, January and February were made by Miss E. H. Swallow according to Schützenberger's method, as finally adopted by him. The following determinations were made to test the accuracy of the process:—

No. 1. Cochituate water, as drawn in the laboratory of the Institute of Technology. The temperature of the water was 7° C. The results obtained were—

|                   | By gas analysis. | By titration. |                                   |
|-------------------|------------------|---------------|-----------------------------------|
| Nitrogen . . .    | 16.69            | —             | } Cubic centimetres<br>per liter. |
| Oxygen . . .      | 8.13             | 8.16          |                                   |
| Carbonic acid . . | 1.47             | —             |                                   |
|                   | <hr/> 26.29      |               |                                   |

No. 2. Cochituate, drawn January 17. Temperature 5°  
C. The results obtained were —

|                 | By gas analysis. | By titration. |                                   |
|-----------------|------------------|---------------|-----------------------------------|
| Nitrogen . .    | 16.498           | —             | } Cubic centimeters<br>per liter. |
| Oxygen . .      | 7.674            | 7.82          |                                   |
| Carbonic acid . | 1.704            | —             |                                   |
|                 | <hr/> 25.966     |               |                                   |

APPENDIX B.  
*Analysis of Charles River Water made by J. M. MERRICK. [See page 95.]*

| Number. | LOCALITY.                                 | DATE.             | PARTS PER 100,000. |          |        | GRAINS PER U. S. GALLON. |          |        |
|---------|-------------------------------------------|-------------------|--------------------|----------|--------|--------------------------|----------|--------|
|         |                                           |                   | Inorganic.         | Organic. | Total. | Inorganic.               | Organic. | Total. |
|         |                                           |                   |                    |          |        |                          |          |        |
| 2       | Above Dedham . . . . .                    | May 13 . . . . .  | 2.35               | 2.41     | 4.76   | 1.37                     | 1.41     | 2.78   |
| 9       | " . . . . .                               | June 9 . . . . .  | 1.96               | 2.39     | 4.35   | 1.14                     | 1.40     | 2.54   |
| 1       | Cow Bay, side and centre . . . . .        | May 13 . . . . .  | 1.97               | 2.42     | 4.39   | 1.15                     | 1.41     | 2.56   |
| 6       | " centre . . . . .                        | " 26 . . . . .    | 2.38               | 2.30     | 4.68   | 1.39                     | 1.34     | 2.73   |
| 7       | " . . . . .                               | June 9 . . . . .  | 2.84               | 2.30     | 5.14   | 1.66                     | 1.34     | 3.00   |
| 12      | " . . . . .                               | " 23 . . . . .    | 3.13               | 1.96     | 5.09   | 1.83                     | 1.14     | 2.97   |
| 21      | " . . . . .                               | July 7 . . . . .  | 3.19               | 2.45     | 5.64   | 1.86                     | 1.43     | 3.29   |
| 25      | " (after rain) . . . . .                  | " 21 . . . . .    | 3.41               | 1.54     | 4.95   | 1.99                     | 0.90     | 2.89   |
| 29      | " . . . . .                               | Aug. 11 . . . . . | 3.26               | 1.75     | 5.01   | 1.90                     | 1.02     | 2.92   |
| Y.      | Needham Bridge . . . . .                  | " 14 . . . . .    | 3.32               | 2.03     | 5.35   | 1.94                     | 1.18     | 3.12   |
| 3       | Waltham pump-basin . . . . .              | May 22 . . . . .  | 4.95               | 1.52     | 6.47   | 2.89                     | 0.89     | 3.78   |
| 4       | Waltham, River, side and centre . . . . . | " 22 . . . . .    | 2.43               | 2.04     | 4.47   | 1.42                     | 1.19     | 2.61   |



## APPENDIX III.

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### SURVEY OF THE MYSTIC WATER-SHED.

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#### CITY OF BOSTON.

IN BOARD OF ALDERMEN, March 23, 1874.

"*Ordered*: That the Joint Standing Committee on Water be requested to have accurate surveys made under the direction of the City Engineer, to ascertain the water-shed of Mystic Pond, — the expense of procuring said surveys to be charged to the appropriation for additional water supply."

---

April 16, 1874.

The survey and estimate of area, made in obedience to the above order, are just finished, and give the following results: —

The area of the water-shed of Mystic Upper Lake, from which the Charlestown works receive their supply, is 27.75 square miles.

The area, after deducting the water surfaces of the lake and proposed storage basins, to offset evaporation from these surfaces, is 26.22 square miles.

At the northern end of the basin is a small meadow, which, from October 25 to April 25, is flooded to form a mill pond, and during that time drains into the Ipswich river,



while for the rest of the year, or during the warm months, it drains into the Abajonna.

The character of this ground, and the conditions governing its use, render it nearly or quite valueless as an aid to the Mystic supply in a dry season. Its area is 0.58 of a square mile.

J. P. D.